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15TBIP-C082044-02

차량탑재형 차선도색 품질검사장치

최종보고서

2016. 9. 29.

주관연구기관 / (주)로드텍

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제 출 문

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‘차량탑재형 차선도색 품질 검사장비 개발’(연구개발 기간 : 2014.09. ~ 2016. 09.) 과제의 최종보고서 1부를 제출합니다.

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동의합니다.

보고서 요약서

과제 고유 번호	15TBIP-C082044-02	해당 단계 연구 기간	2014. 09. ~ 2016. 09	단계구분	
연구사업명	중사업명	국토교통기술사업화 지원사업			
	세부사업명	구매조건부 사업			
연구과제명	대과제명				
	세부과제명	차량 탑재형 차선도색 품질 검사장치 개발			
연구책임자	문 형 철	해당단계 참여 연구원 수	총: 11명 내부: 11명 외부: 명	해당단계 연구개발비	정부:200,000천원 기업:133,500천원 정부 외: 천원 계:333,500천원
		총 연구기간 참여 연구원 수	총: 11명 내부: 11명 외부: 명	총 연구개발비	정부:400,000천원 기업:267,000천원 정부 외: 천원 계:667,000천원
연구기관명 및 소속 부서명	주식회사 로드텍			참여기업명	
국제공동연구	상대국명:			상대국 연구기관명:	
위탁연구	연구기관명:			연구책임자:	
요약				보고서 면수: 243	
운전자에게 시인성은 안전운전에 매우 중요한 요건이다. 우천시, 혹은 안개구간에서 운전자의 전방 시야는 맑은 날에 비해 현저히 저하 되어 교통사고의 원인이 되고 있다. 또한 국내 도로망의 신설, 확장으로 인한 차선도색 유지관리 면적 및 비용이 지속적으로 증가하고 있다. 차선의 휘도 뿐 아니라 차선의 노후화, 동절기 제설작업등으로 차선도색의 물리적 파손이 발생되어 운전자가 차선을 제대로 인지하지 못하는 결과를 초래하고 있다. 차선 휘도에 있어 경찰청 관리 규정에는 도시 외곽 지역의 경우 백색선의 밝기는 100mcd/m²/lux, 황색선은 70mcd/m²/lux 이하로 떨어지면 다시 칠하도록 규정하고 있다. 그러나 도로준공에 있어 교통이 개방되지 않은 상태에서만 품질검사를 시행 할 수 있으며, 공용중인 도로에서는 측정할 수 없는 것이 현실이다. 이에 본 연구에서는 외산장비 위주로 구성되어 있는 차량형 차선도색 평가장비를 국산화하여 차선도색 상태, 재귀반사 휘도를 측정할 수 있는 장비를 개발하고 차선품질 유지관리 프로그램을 개발하여 체계적인 차선 유지관리의 기초를 제공한다.					

〈 요약문 〉

연구의 목적 및 내용	현재 국내에서 차선의 휘도나 도색상태를 평가하는 조사장비는 전량 국외에서 도입하고 있을 뿐 아니라, 도로 및 차선상태를 관리하는 유관기관 중에서도 이러한 측정장비를 보유 운영하고 있는 기관이 매우 드문 실정이다. 이에 본 연구과제를 통해 측정장비의 국산화를 이루고, 체계적인 차선 유지관리의 기초를 제공하도록 한다. 본 연구개발의 최종 목표는 크게 3가지로 요약된다. 차선도색 재귀반사 휘도 측정기와 차선도색 상태 측정기를 개발하고, 이로부터 측정되는 데이터를 효율적으로 관리해주는 차선품질유지관리 프로그램을 개발하는 것이다.				
연구개발성과	차선도색 상태 측정기, 차선도색 재귀반사 휘도 측정기, 차선품질 유지관리 프로그램 개발				
연구개발성과의 활용계획 (기대효과)	• 과제 산출물인 “차량탑재형 차선도색 품질 검사장치”를 성공적으로 수행하여 해당기관에 물품판매에 그치는 것이 아니라 구매기관과 적극적 의사소통을 통해 응용 및 확장된 신규 제품개발을 공동으로 수행. • 지속적인 결과물의 성능개선 및 제품으로써의 기술 및 가격경쟁력을 확보하여 국내 뿐 아니라 세계적인 경쟁력을 갖춘 제품으로 공동사업을 추진하는것이 바람직 할 것으로 판단됨. • 개발도상국의 도로안전도평가 iRAP프로그램에 국내유관기관(한국국제협력단 등)과 협력하여 차선평가 방법으로 채택 추진.				
핵심어 (5개 이내)	차선도색	휘도	재귀반사	탈리	관리

< SUMMARY >

Purpose & Contents	Lane marking luminance measuring equipment(Retroreflectometer) was to assess the state of the entire country have been introduced in road and lane as well as to manage. Measuring equipment, such as the related agencies operating agency is very rare. Through this research task, the measuring equipment through the localization of the systematic maintenance to provide the basis of the lane making. The final goal of this research and development is three. The first goal is development retroreflectometer. The second goal is lane marking paint condition measuring device development. The third goal is quality maintenance program.					
Results	Device for evaluating lane marking paint condition, Retroreflectometer, and lane marking maintenance program.					
Expected Contribution	Carry out equipment for government agencies, and extended develop new products. The global competitiveness and plan to promote joint projects with other companies. Improvement of performance, technology and price competitiveness as a global as well as local competitive as a joint venture.					
Keywords	Lane marking	Luminance	Retroreflectomete r	Fall out	Lane management	

< Table of Contents >

1. Abstract	1
2. Current technology development	7
3. Research and development content	11
4. Contribution and related field goals	74
5. The Applicable Planning of R&D outcome	80
6. Science and technology information collected in research	85
7. Security grade of R&D outcome	231
8. Registered research facilities and equipment at NTIS	233
9. safety action	235
10. Typical performance of research and development	237
11. Other matters	239
12. References	241

< 목 차 >

1. 연구개발과제의 개요	1
2. 국내외 기술 개발 현황	7
3. 연구 수행 내용 및 성과	11
4. 목표 달성도 및 관련 분야 기여도	74
5. 연구개발성과의 활용 계획	80
6. 연구 과정에서 수집한 해외 과학기술 정보	85
7. 연구개발성과의 보안등급	231
8. 국가과학기술종합정보시스템에 등록한 연구시설·장비 현황	233
9. 연구개발과제 수행에 따른 연구실 등의 안전 조치 이행 실적	235
10. 연구개발과제의 대표적 연구 실적	237
11. 기타 사항	239
12. 참고 문헌	241

제1장. 연구개발과제의 개요

1. 연구개발 목적

차선의 정의는 도로교통법 제2조 7항에 명시되어 있으며 차로와 차로를 구분하기 위하여 그 경계지점을 안전표지로 표시한 선을 의미한다. 차로는 차마가 한 줄로 도로의 정하여진 부분을 통행하도록 구역을 구분한 것이다. 따라서 차선은 차량 통행의 질서를 유지하고 안전을 기하기 위한 주행 폭을 육안으로 식별할 수 있도록 점선 또는 실선의 형태로 구분한다. 운전자에게 있어 차선은 타 차량의 주행방향, 회전정보 등을 미리 예측하는 한편 본인의 주행방향 및 의도를 타 차량에게 전달하는 수단이 된다. 따라서 차선의 시인성 확보 여부는 교통사고 위험과 직접적인 관계가 있으며, 특히 시인성이 떨어지는 야간의 경우 사고의 위험성은 더욱 증가하게 된다.

차선의 시인성은 운전자 전방 시야에서 확인할 수 있는 차선의 광원에 대한 반사정도(휘도, luminance)로 나타낼 수 있으며, 차선의 휘도는 차륜에 의한 마모, 기상작용에 의한 도로의 노화, 제설작업 등에 의한 손상 및 탈리 등으로 인해 점차 낮아지게 된다. 도로연장의 지속적 증가(그림 1.1) 및 교통안전사고에 관한 사회적 관심과 더불어 차선의 유지관리 또한 중요시되고 있어, 차선의 휘도 기준을 강화하는 등의 노력이 수반되고 있다. 하지만 차선의 품질을 평가함에 있어 그림 1.2와 같은 휴대용 휘도 측정기가 주로 활용되고 있어 유지관리용으로서 신속성이 결여될 수 밖에 없다.



그림 1.1 국내 도로 총연장 증가 추이(통계청, 2012)



그림 1.2 휴대용 휘도 측정기

대표적인 도로관리 주체인 한국도로공사, 국토관리사무소 및 각 지자체에서 관리하는 도로 연장을 고려하였을 때 휴대용 장비로는 Network Level에서 신속하게 차선의 상태를 평가할 수 없다. 국외의 경우 차량 측면에서 일정 각도로 차선의 휘도를 측정할 수 있는 장비가 개발되어 운용중에 있으나 대부분 차선의 밝기 및 휘도 측정에 주안점을 두고 있는 실정이다. 또한 차선 도료의 품질이나 설치 규격이 국내 기준과 상이할 수밖에 없어 국내 도로환경에 최적화된 차량형 차선도색 품질검사장치의 개발이 시급한 실정이다. 차선 품질평가의 결과가 유지관리에 효율적으로 활용되기 위해서는 GPS모듈, 거리측정장치(DMI) 등을 이용한 정확한 측정위치를 관리자에 제공하여야 한다. 부가기능으로써 차선의 도막 두께를 측정하여 적정하게 설치되었는지의 여부, 차선의 공용수명 등을 예상할 수 있어 차선 유지관리 전략 수립 및 효율적인 예산 분배가 가능해진다.

본 연구과제의 목적은 차량형으로 개발된 외산 장비의 휘도 측정 기술을 국산화, 실용화하여 실제 차선 유지관리에 투입할 수 있는 국산 차량탑재형 차선도색 품질검사장치를 개발하는 것이다. 이에 본 연구과제에서는 태양광 및 일조량에 관계없이 레이저를 광원으로 사용하여 주/야간 구분 없이 도막 두께, 탈리 면적, 휘도 등 차선의 상태를 종합적으로 측정할 수 있는 기술개발을 목표로 하고 있으며, 측정된 차선데이터와 더불어 현위치, 주변 시설물 및 현황 사진 등을 총괄적으로 다루는 차선 유지관리 프로그램을 개발한다.

2. 연구개발의 필요성

운전자에게 시인성은 안전운전에 매우 중요한 요건이다. 우천시, 혹은 안개구간에서 운전자의 전방 시야는 맑은 날에 비해 현저히 저하되어 교통사고의 원인이 되고 있다. 또한 국내 도로망의 신설, 확장으로 인한 차선도색 유지관리 면적 및 비용이 지속적으로 증가하고 있다. 차선의 휘도 뿐 아니라 차선의 노후화, 동절기 제설작업 등으로 차선도색의 물리적 파손이 발생되어 운전자가 차선을 제대로 인지하지 못하는 결과를 초래하고 있다. 그림 1.3은 차선 품질의 중요한 성능인 휘도와 도색수준이 불량한 구간의 예를 나타낸 것이다.



(a) 회도불량



(b) 도색불량

그림 1.3 차선 도색의 품질불량 예

우리나라 국도의 차선 도색에 매년 150억 원 이상의 예산이 투입되고 있으며(국토교통부, 2012), 한국도로공사는 차선도색 예산을 기존예산에 비해 2배 가까이 늘린 250억 원을 매년 투입할 계획을 수립하였다(한국도로공사, 2014).

위의 대표적인 사례에서 알 수 있듯이 차선은 도로이용자 안전에 큰 영향을 미치는 도로안전시설 중 하나이다. 국내에서도 이러한 인식 개선이 이루어지고 있으며, 이를 뒷받침할 관련 예산의 확충 등이 이루어지고 있다. 그러나 신설 차선도색에 예산 및 관심이 집중되고 있는 단점이 있어, 공용중인 차선에 대한 유지관리가 체계적으로 이루어지지 않은 것이 현실이다. 따라서 본 과업을 통해 공용중인 차선도색의 체계적인 관리가 시행 될 수 있는 시스템을 개발하고자 한다.

차선 회도에 있어 경찰청 관리 규정에는 도시 외곽 지역의 경우 백색선의 밝기는 $80\text{mcd}/\text{m}^2/\text{lux}$, 황색선은 $50\text{mcd}/\text{m}^2/\text{lux}$ 이하로 떨어지면 다시 칠하도록 규정하고 있다. 그러나 도로준공에 있어 교통이 개방되지 않은 상태에서만 품질검사를 시행할 수 있으며, 공용중인 도로에서는 측정할 수 없는 것이 현실이다. 이렇게 공용중인 도로에서 차선의 회도 관리가 제대로 이루어지지 않으면, 우천시 도로의 배수 불량 및 차선 도색의 노후화로 운전자가 주행차로를 제대로 인지하지 못해 추돌사고 및 차로 이탈의 사고 위험성이 높다. 미국 및 유럽 차선도색 회도기준은 표 1.1과 같다.

표 1.1 미국 및 유럽 차선도색 휘도기준(한국도로공사, 2008)

(단위 : mcd/m²/lux)

구분	미국(ASTM)	유럽(CEN)
백색	250	100~300
황색	175	80~200

국내에서는 한국도로공사, 경찰청, 서울시 등 각 기관별 별도의 차선재귀반사 휘도품질기준을 제정, 개별적으로 적용하였으나, 관리 효율성 및 법적근거를 확보하기 위해 2014년 경찰청 기준으로 일원화되었다(표 1.2).

표 1.2 국내 차선도색관련 품질기준(경찰청, 2014)

(단위 : mcd/m²/lux)

조사각	관찰각	구분	최소 재귀반사성능			비고
			백 색	황 색	청 색	
88.76° (1.24°)	1.05° (2.29°)	설치시	240	150	80	기준
		재설치 시기	100	70	40	권장
		우천(습윤)시	100	70	40	권장

국도 및 고속도로에 국한하여 차선유지관리비용은 매년 400억 이상의 예산이 투입되는 중요 도로안전시설이다. 그림 1.4에 나타난 바와 같이 우리나라 도로연장은 2013년 기준 약 106,000km로, 도로연장의 증가세는 둔화되었으나 1960년 대비 약 3배정도 증가되었다.

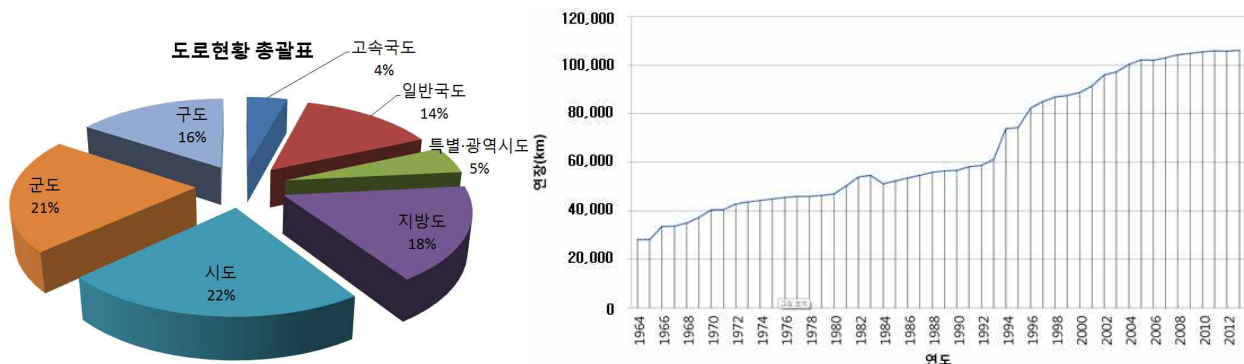


그림 1.4 우리나라 도로 구성비율 및 연장(국토교통부, 2014)

2012년도의 주간/야간의 차량 교통량 대비 차선의 시인성 확보 여부에 따른 사고(중앙선 침범)비율은 그림 1.5와 같다. 야간 교통량이 주간 교통량의 1/2임에 해당함에도 불구하고 야간

시 교통사고는 주간 교통사고 건수보다 월평균 약 400건 가량 많이 발생한 것을 나타낸다.

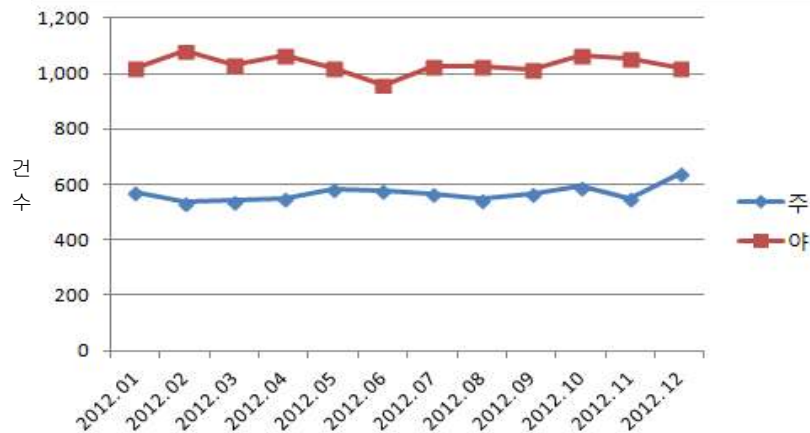


그림 1.5 국내 교통량 대비 사고건수
(출처 통계청, 주/야 교통량비=2:1, 사고유형 중앙선 침범)

도로연장의 증가로 인해 도로에 설치된 다양한 안전시설의 유지관리도 중요한 사안으로 대두되고 있으며, 매년 400억 이상의 국가 예산이 투입되는 차선유지관리를 객관적이며 과학적으로 평가할 수 있는 시스템이 요구된다. 앞서 언급한 바와 같이 현재 국내에서는 이러한 차선의 휘도나 도색상태를 평가하는 조사장비의 전량을 국외에서 도입하고 있을 뿐 아니라, 측정장비를 보유하여 운영하고 있는 기관의 수도 매우 드문 실정이다. 이에 본 연구과제를 통해 측정장비의 국산화를 이루고, 향후 체계적인 차선유지관리의 기초를 확립할 필요가 있다.

3. 연구개발 범위

본 연구개발의 최종 목표는 크게 3가지로 요약된다. 차선도색 재귀반사 휘도 측정기와 차선도색 상태 측정기를 개발하고, 이로부터 측정되는 데이터를 효율적으로 관리해주는 차선품질유지관리 프로그램을 개발하는 것이다. 각 최종 목표를 달성하기 위한 개발기술의 목표성능을 바탕으로 연구개발의 범위를 설정하였으며, 각 주요 항목의 세부 범위는 표 1.3~1.5와 같다.

표 1.3 차선도색 상태 측정기 개발을 위한 연구범위 및 세부목표

연구범위	개발기술 목표성능	기존기술 성능	비 고
광원	레이저	없음	
측정 속도	14,000회 이상/초	없음	
가로 및 세로 분해능	2mm 이하	없음	
높이 분해능	0.5mm 이하	없음	
조사 속도	100km/h 이상	없음	
측정 조건	주간 및 야간	없음	
스캔 폭	50cm 이상	없음	

표 1.4 차선도색 재귀반사 휘도 측정기 개발을 위한 연구범위 및 세부목표

구분	개발기술 목표성능	기존기술 성능	비 고
입사각	88.76도	88.76도	
측정각(관찰각)	1.05도	1.05도	
측정 속도	30회 이상/초	20회/초	
측정 정확도 (정지측정기 대비)	90% 이상	77~95%로 다양함	
측정 조건	주간 및 야간	주간 및 야간	
스캔 폭	1.1m	1 ~ 1.1m	
조사궤적 조사	GPS 연동	일부장비 기능 있음	
측정 범위	10 ~ 1000mcd/m ² /lux	5~4000mcd/m ² /lux	차선 재귀반사 기준 (70~420mcd/m ² /lux)
주변영상 획득	10m 마다의 전방영상 획득	일부장비 기능 있음	

표 1.5 차선품질 유지관리 프로그램 개발을 위한 연구범위 및 세부목표

구분	개발기술 목표성능	기존기술 성능	비 고
웹 GIS맵을 이용한 조사위치 및 상태표시	국내 웹 GIS 이용	타 프로그램 동일기능 있음	*기존 기술: 도로관리 프로그램
이력관리 기능	기 조사데이터 누적 기록	동일기능 있음	"
불량구간/정상구간 표시기능	노선, 차로별 생성	동일기능 있음	"
보수물량 제시 기능	차선종류, 재료별 단가 반영	동일기능 있음	"
보고서 생성 기능	상태, 위치, 보수 물량 등	동일기능 있음	"
Stand-alone 시스템	관리자 독립 PC 운영 기능	동일기능 있음	"
주변영상 연동	10m 마다 획득된 전방위(360도영상) 연동 표현	전방영상	"

제2장. 국내외 기술 개발 현황

1. 관련 분야의 국내 연구 및 기술개발동향

가. 국가연구개발사업 유사연구 검토

본 과제와 관련한 유사/중복 과제를 검토한 결과, 과제의 내용과 직접적인 관련 있는 항목이 없는 것으로 확인된다.

-사이트 : www.ntis.go.kr (국가R&D사업관리서비스)

-키워드 : 휘도 측정기, 휘도, 도로, 시인성

-기간 : 1998년 ~ 2016년

나. 관련 연구문헌 검토

노면 휘도 측정을 키워드로 한 주요 발행물 검색결과를 표 2.1에 정리하였다. 2000년대 초기에는 도로 시인성의 안전기준에 대한 기준 확립 및 주요 위험 구간인 터널에 대한 많은 연구가 이루어졌으나, 점차적으로 휘도 측정에 대한 기술 및 분석기법을 중심으로 다양한 연구가 진행되고 있는 것으로 나타났다.

표 2.1 차선험도관련 발행물 검색 결과

제목	년도	분류
도로 조명에 의한 조도 및 휘도 분포 계산 프로그램 개발	1998	논문
도로 포장 시료의 종류와 마모에 따른 반사특성의 변화	1999	논문
도로조명설계에 있어서 휘도-조도 환산계수 적용에 관한 연구	1999	논문
Lightscape를 이용한 노면 균제도 연구	2002	논문
차량을 이용한 터널조도 및 휘도 측정시스템 개발	2005	논문
차량 계측 시스템을 이용한 터널의 조도 및 휘도 실측값 분석	2005	논문
수도권 시내도로 조명현황 측정 및 분석	2006	논문
터널조명 계측용 차량시스템 개발에 관한 연구	2006	논문
고성능 터널조명 측정시스템	2007	논문
도로조명 측정을 위한 2분할 측정시스템에 대한 연구	2007	논문
고성능 터널조명 측정시스템 개발	2008	논문
CDM Lamp를 이용한 도로의 터널 조명 개선에 관한 연구	2009	논문
조도 및 휘도 측정차량을 활용한 최적의 터널조명 운영방법 연구	2009	논문
노면표시 형태별 재귀반사 비교평가에 관한 연구	2010	논문
차선인식을 이용한 도로 휘도 측정 장치의 계산 영역 추출 방법	2013	논문
휴대용 도로노면 반사특성 측정 장치 개발을 위한 기초 연구	2013	논문
도로조명의 실측과 시뮬레이션의 오차보정계수 산출	2014	논문
터널구간 조명 및 교통안전성 개선방안 수립 기초연구	2003	도서
야간 시인성 증진을 위한 도로안전시설 개발 연구보고서	2006	도서
노면표시 반사성능 기준에 관한 연구	2012	도서
노면표시 재귀반사휘도 측정시스템 구축 및 시험방법에 관한 연구	2013	도서

다. 관련 기술(특허) 현황 검토

차선 휘도 측정과 관련하여 터널내 조도 및 휘도 측정시스템이 있으나, 이는 일반적인 차선의 휘도측정(터널내 조명에 따른)과 관련된 기술이며, 본 과제에서 목표로 하는 재귀반사 휘도 측정기술과는 다소 상이하다. 이 외 휘도측정과 관련한 도서 및 논문은 지속적으로 발행되는 것으로 분석되었다.

표 2.2 국내 특허 현황 (출처:키프리스)

제목	출원번호/일자	출원인
터널 내 조도 및 휘도측정시스템	1020060123173 (2006.12.06)	강원대학교산학협력단 김동조

그림 2.1은 전반적인 연구 및 기술개발 추이를 그래프로 도시한 것이다. 차선 도색과 관련된 연구는 꾸준히 진행이 되고 있는 것으로 나타났으나, 실제 기술개발로 연결되어 실용화 또는 사업화 단계까지 진행된 경우는 거의 없는 것으로 나타났다.

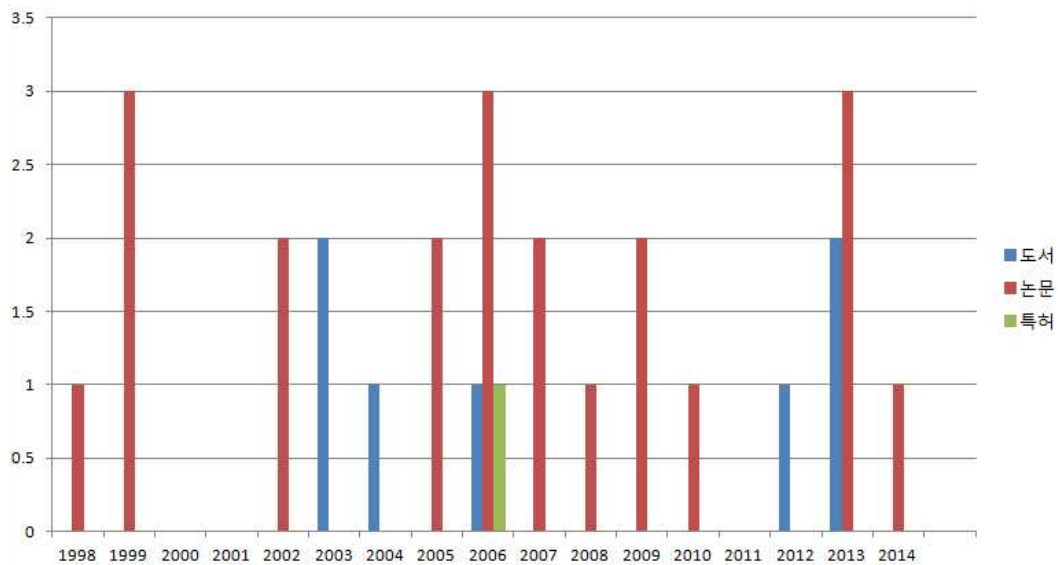


그림 2.1 관련 발행물 (출처:국회도서관, 노면휘도 측정)

차선의 휘도 측정 이외에 부가적으로 필요한 기술은 앞서 언급한 바와 같이, 거리측정기술 및 표면 영상 취득 및 처리 기술이 필수적이다. 표 2.3은 관련된 기술의 주요 내용과 기능을 정리한 자료이다.

표 2.3 휘도 측정 이외 관련 기술 개발 현황

개발과정	일 자	주요 진행내용	개발주체
정밀거리측정기 개발	2008년	• 100km/h 이상의 속도에서 1mm 분해능으로 거리 측정 • 8개의 개별적 등간격 트리거 출력 기능 • 구간 거리 측정 기능 • 순간 거리 캡취 기능	(주)로드텍
레이저를 이용한 도로 표면 영상 취득 모듈 개발	2008년	• 적외선 레이저를 이용하여 1mm 간격으로 도로 표면 영상을 촬영하여 도로 상태 분석 • 주야 조사 기능	(주)로드텍
등간격 도로 현황 영상 영상 측정 모듈 개발	2008~2010년	• 등간격으로 도로의 전방 영상을 취득 • 등간격으로 도로의 전방위(360도) 영상을 취득	(주)로드텍

2. 관련 분야의 국외 기술개발 현황

가. 관련 기술(특허) 현황 검토

표 2.4는 차선도색과 관련된 국외 특허 현황을 정리한 것이다. 다차선의 휘도측정을 위한 기술 및 관련 시스템, 동적 상태에서 차선의 모양, 위치, 사이즈 등을 측정할 수 있는 기술 등이 특허로 출원되어 있음을 알 수 있다.

표 2.4 국외 특허 현황 (출처:WIPO국제사무국)

제목	출원번호	출원인
SYSTEM AND METHOD FOR MULTILINE RETROREFLECTION MEASUREMENT OF ROAD MARKINGS	PCT/EP2013/077772	INSTITUTE OF TECHNOLOGY BLANCHARDSTOWN
DYNAMIC METHOD AND DEVICE FOR MEASURING THE LUMINANCE AND BACK-REFLECTION OF ROAD MARKINGS AND SIGNS AND OBTAINING THE SHAPE, POSITION AND DIMENSIONS THEREOF	PCT/ES2012/070791	FUNDACIÓN CIDAUT
Measurement of the luminance of a road surface	10160723	ROCH SERVICE
Device and method for measuring the retro-reflected luminance coefficient of road markings	09168888	INST FRANCAIS DES SCIENCES ET TECHNOLOGIES DES TRANSPORTS DE L AMENAGEMENT ET DES RESEAUX
ROAD COVERING BRIGHTNESS MEASURING METHOD	2004114694/28	

나. 차량형 차선조사 장비 시판품 검토

국외의 경우, 좁은 영역의 휘도 측정계측 장비부터 넓은 영역의 휘도를 측정할 수 있는 제품까지 개발이 되고 있으며, 넓은 영역의 휘도를 단위 Frame으로 쌓아 동영상화하는 형태의 제품도 시장에 출시가 되어 있다. 대표적인 차량에 탑재 가능한 해외 모델 세 종류를 표 2.5에 비교하여 정리하였다.

표 2.5 국외 차량탑재형 차선 재귀반사휘도 측정기 예

모델명	LaserLUX	LTL-M	Zehntner
website	http://www.roadvista.com/	http://roadsensors.madebydelta.com/	http://www.zehntner.com
제품 사진			

제3장. 연구 수행 내용 및 성과

1. 차선도색 상태 측정기 개발

차선도색 상태를 판단하기 위해서는 도색의 탈리 정도를 확인할 수 있는 이미지 데이터를 취득할 수 있어야 하며, 도색의 두께를 확인할 수 있는 변위 데이터 또한 취득할 수 있어야 한다. 이 두가지 정보를 동시에 취득할 수 있는 방법 중 하나가 3차원 레이저 변위측정 방식이다. 이 방법은 도로의 차선을 높낮이 정보인 변위데이터를 취득함과 동시에 반사율 데이터로부터 차선의 이미지 데이터를 취득할 수 있다. 따라서 본 연구에서는 차선도색 상태를 측정하기 위해 열악한 환경인 도로포장면에서 외부요인(주간, 야간의 태양광, 가로등 및 차량 조명등)에 영향을 최소화한 3차원 레이저 변위측정기를 개발하였다. 3차원 레이저 변위측정기의 기본 개념은 그림 3.1 및 3.2와 같다.

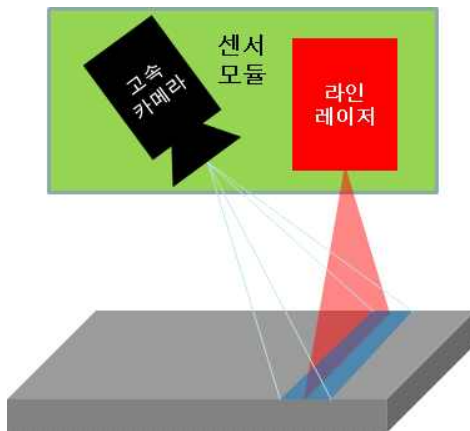


그림 3.1 변위 측정개념도

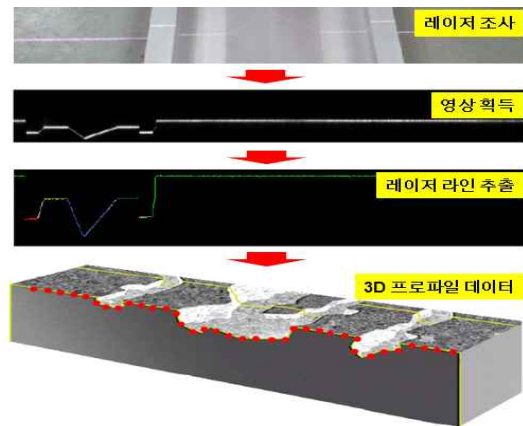


그림 3.2 3차원 데이터 획득 순서

라인 레이저를 노면에 조사하면 노면 형상을 따라 레이저 라인이 형성되고, 이를 카메라로 촬영한 뒤 이미지 프로세싱을 통해 노면의 3차원 형상을 획득한다. 이때 획득된 영상에서 레이저 라인의 밝기값(intensity)을 이용하여 이미지 데이터 또한 생성할 수 있다.

가. 센서 장착 높이 결정

차선도색 상태 측정기 개발에 있어 센서의 장착 높이는 카메라 화각 및 라인레이저 방사각 선정에 있어 주요한 영향 요소이다. 따라서 각 구성품의 사양을 선정하기 이전에 먼저 센서 장착 높이가 결정되어야만 한다. 센서의 장착 높이별 라인 레이저의 방사각과의 관계는 그림 3.3과 같다. 한 예로써, 동일한 스캔폭을 확보하기 위해 센서의 장착높이가 낮아질수록 방사각은 커져야 한다.

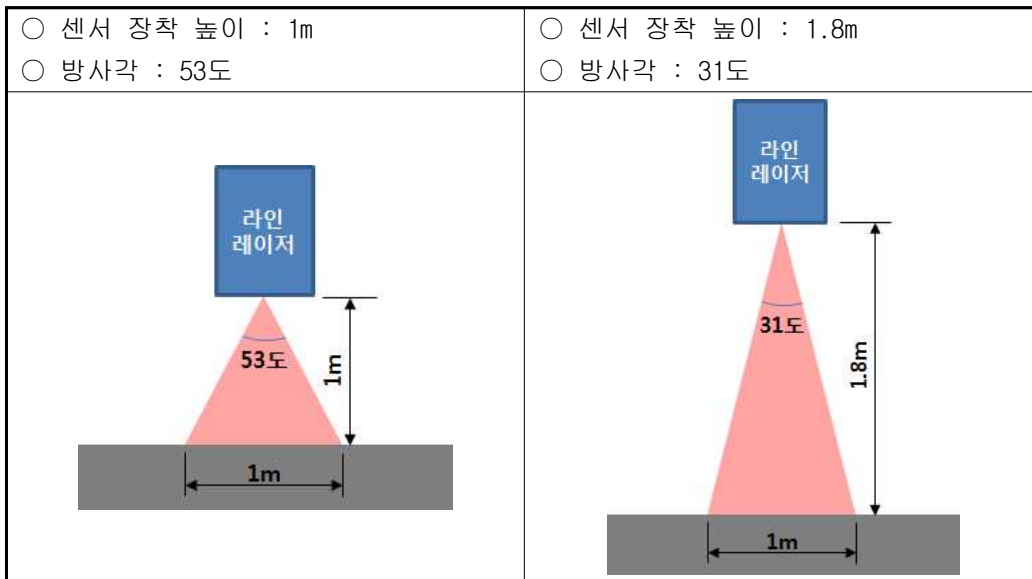


그림 3.3 센서 장착높이별 레이저 방사각 예

하지만 레이저 라인의 방사각이 커질수록 손실되는 빛 에너지가 커져 고른 라인 영상을 얻기가 힘들어진다. 라인 레이저의 에너지 분포가 동일하다고 가정했을 때 라인레이저와 동일 지점에서 촬영된 카메라 영상내의 라인 밝기값(intensity)은 그림 3.4와 같은 분포를 가진다. 즉, 라인레이저를 중심에서 멀어질수록 돌아오는 빛 에너지는 감소한다.

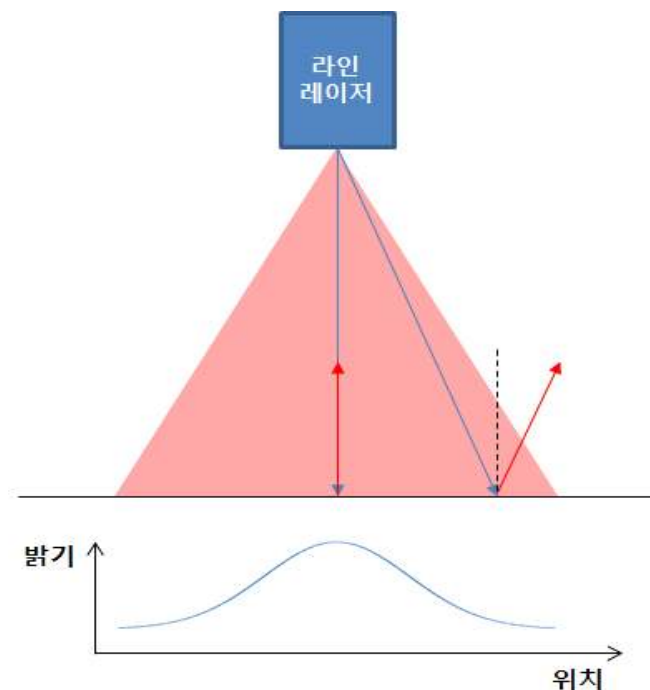


그림 3.4. 방사각에 따른 회귀 빛 에너지

외측 회귀 빛 에너지의 감소를 최소화하고 수광량을 일정하게 유지하기 위해 라인레이저의 방사각은 45도를 넘지 않도록 설정하였다. 적용되는 렌즈와 영상센서 CCD 크기를 고려하여 설치 높이를 1.8m로 결정하였다. 그리고 좀 더 다양한 이동수단에 장착할 수 있도록 설치 가능 높이를 1.5 ~ 1.8m까지 가능하도록 주요 부품의 사양 선정 시 이를 고려하였다.

나. 카메라 선정 및 구매

(1) 카메라 최소사양 결정 및 선정

차선도색 상태 측정기 개발에 있어 카메라는 핵심 센서 중의 하나이다. 고속도로 조사를 감안하여 차선도색 상태 측정기의 최대 조사속도를 80km/h에서 100km/h로 상향조정하여 시작품 제작에 반영하였다. 따라서 최대 100km/h 속도에서 2mm간격의 데이터를 획득하기 위해 요구되는 카메라의 최소 촬영 속도는 13,889frames/sec가 된다. 그림 3.5는 시판 중인 고속카메라의 주요 사양을 정리한 것이며 위와 같은 조건을 만족하는 카메라는 고속 카메라 중 최상위 모델에 속하는 것으로 나타났다. 선정된 모델은 그림 3.6에서 보는 바와 같이 CP80-4-M-500 모델로 CCD(Charge Coupled Device)영역에서 관심영역을 설정(ROI, Region Of Interest)하면 23,000frames/sec 속도로 데이터 획득이 가능하다. 이는 목표 성능인 13,889frames/sec를 상회하는 성능으로, 100km/h 이상의 속도까지 조사가 가능함을 의미한다.

Camera specification				
Model monochrome	CP70-12-M-167	CP80-3-M-540	CP80-4-M-500	CP80-25-M-72
Model color	CP70-12-C-167	CP80-3-C-540	CP80-4-C-500	CP80-25-C-72
CXP channel speed	6,25 Gbit/s CXP-6	5,00 Gbit/s CXP-5	6,25 Gbit/s CXP-6	6,25 Gbit/s CXP-6
CXP connector	DIN 1.0/2.3	BNC	BNC	BNC
Resolution max.	4080 (H) x 3072 (V)	1696 (H) x 1710 (V)	2304 (H) x 1720 (V)	5120 (H) x 5120 (V)
Framerate with full res.	167 fps (8 bit)	540 fps	500 fps	72 fps (10 bit)
Framerate with reduced resolutions	300 fps @4080 x 1690	1000 fps @1200 x 1200	10000 fps @2304 x 80 23000 fps @2304 x 32	284 fps @3000 x 2000 500 fps @1920 x 1080
Image sensor	Global shutter CMOS	Global shutter CMOS	Global shutter CMOS	Global and rolling shutter CMOS
Sensor model	CMOSIS CMV12000	On Semi Lupa 3000	Alexima AM41	On Semi Vita 25k
Exposure time (min.)	28 µs	2 µs	2 µs	100 µs
Active area	22.44 x 16.90 mm ²	13.57 x 13.68 mm ²	16.13 x 12.04 mm ²	23.04 x 23.04 mm ²
Pixel size	5.5 µm square	8 µm square	7 µm square	4.5 µm square
A/D converter	8/10 bit	8 bit	8 bit	8/10 bit
SNR (EMVA1288)	41 dB	42 dB	42 dB	42 dB
Dynamic range	60 dB sensor	49 dB EMVA1288	48 dB EMVA1288	56 dB global shutter 60 dB rolling shutter sensor
Sensitivity	4.64 V/lux.s (with microlenses)	3.8 V/lux.s (with microlenses)	9 V/lux.s	3.3 V/lux.s (with microlenses)

그림 3.5 고속 카메라 사양



그림 3.6 선정된 카메라 외형

(2) 렌즈 선정

조사 차량의 원더링을 고려하여 목표 스캔폭을 50cm로 설정하였지만, 조사 편의를 위해 스캔폭을 1m로 설정하였다. 카메라의 가로 해상도가 2304 pixel이므로 스캔 폭이 1m가 되더라도 목표 가로 분해능인 2mm를 충분히 만족시킬 수가 있다. 1.8m 높이에서 1m 이상을 커버할 수 있는 렌즈 초점거리는 아래 화각 식을 이용하여 구할 수 있다.

$$\text{화각} = 2 \times \tan^{-1} \left(\frac{\text{센서대각선길이}}{2 \times \text{초점거리}} \right) \quad \text{식 3.1}$$

필요한 렌즈의 초점거리는 36mm이하여야 하며, 상용 렌즈 중 25mm렌즈를 선정하였다. 25mm렌즈를 사용했을 때 1.5 ~ 1.8m의 센서 장착 높이에서 스캔되는 폭은 그림 3.7과 같이 1.2 ~ 1.4m로 1m 이상이 커버됨을 알 수 있다.

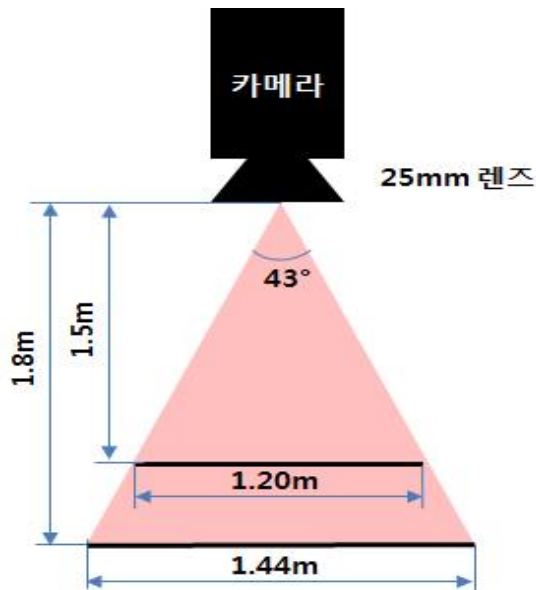


그림 3.7 25mm렌즈 적용 시 거리별 스캔폭

다. 레이저 선정

3차원 레이저 변위측정기 구성에 있어 라인레이저는 변위데이터 정확도에 많은 영향을 미치는 요소이다. 라인레이저는 선폭이 가늘수록 변위데이터의 정확도 및 이미지 선명도가 향상되며, 밝기 분포가 고를수록 이미지가 균일해진다(그림 3.8~10).

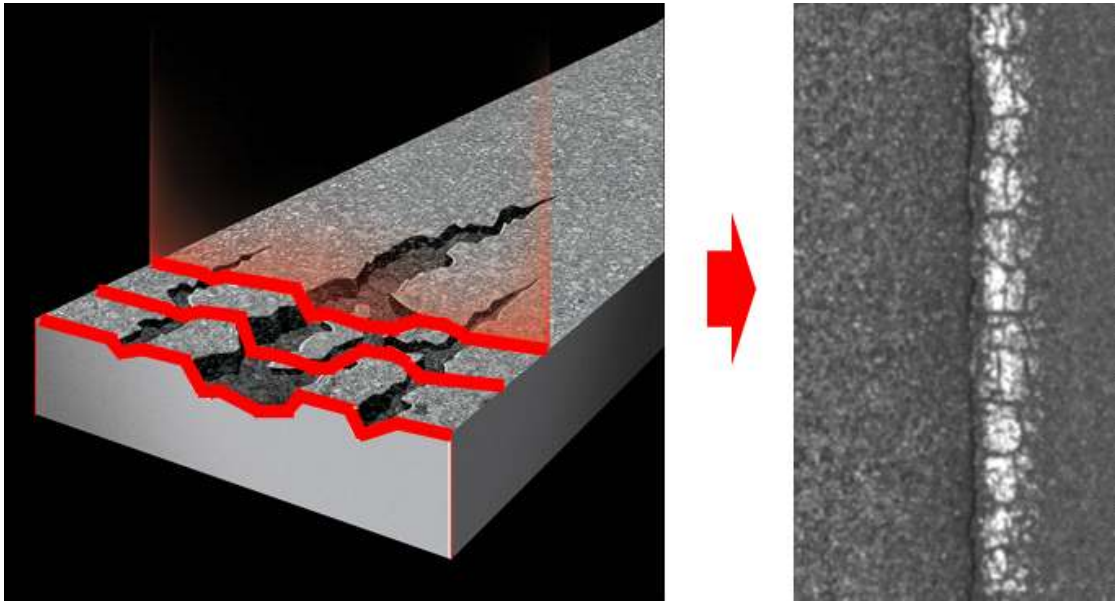


그림 3.8 굽은 라인레이저를 사용했을 때의 획득 이미지

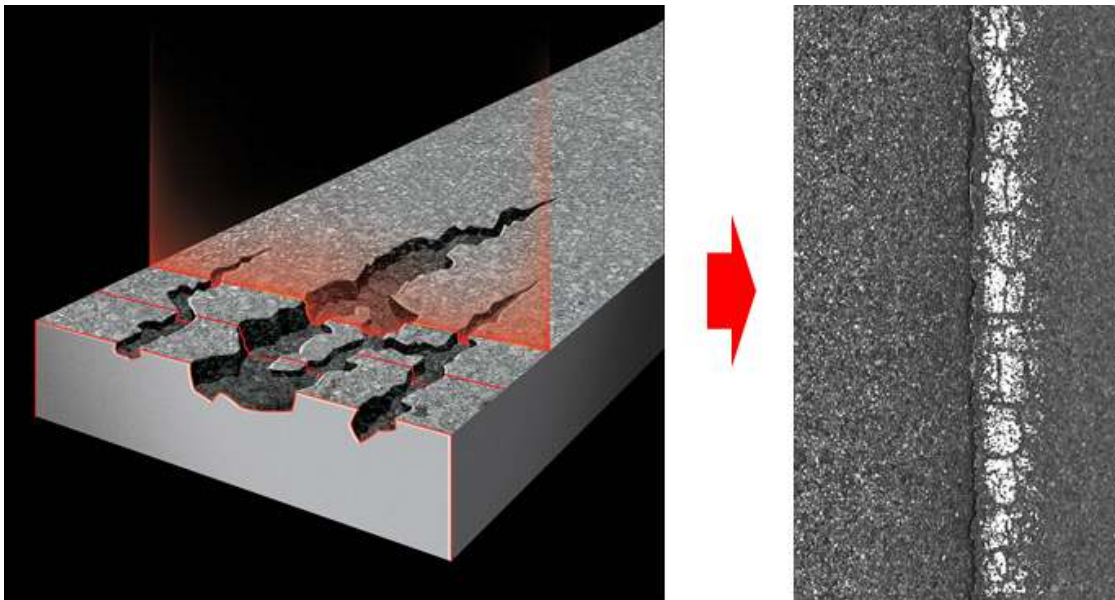


그림 3.9 가는 라인레이저를 사용했을 때의 획득 이미지

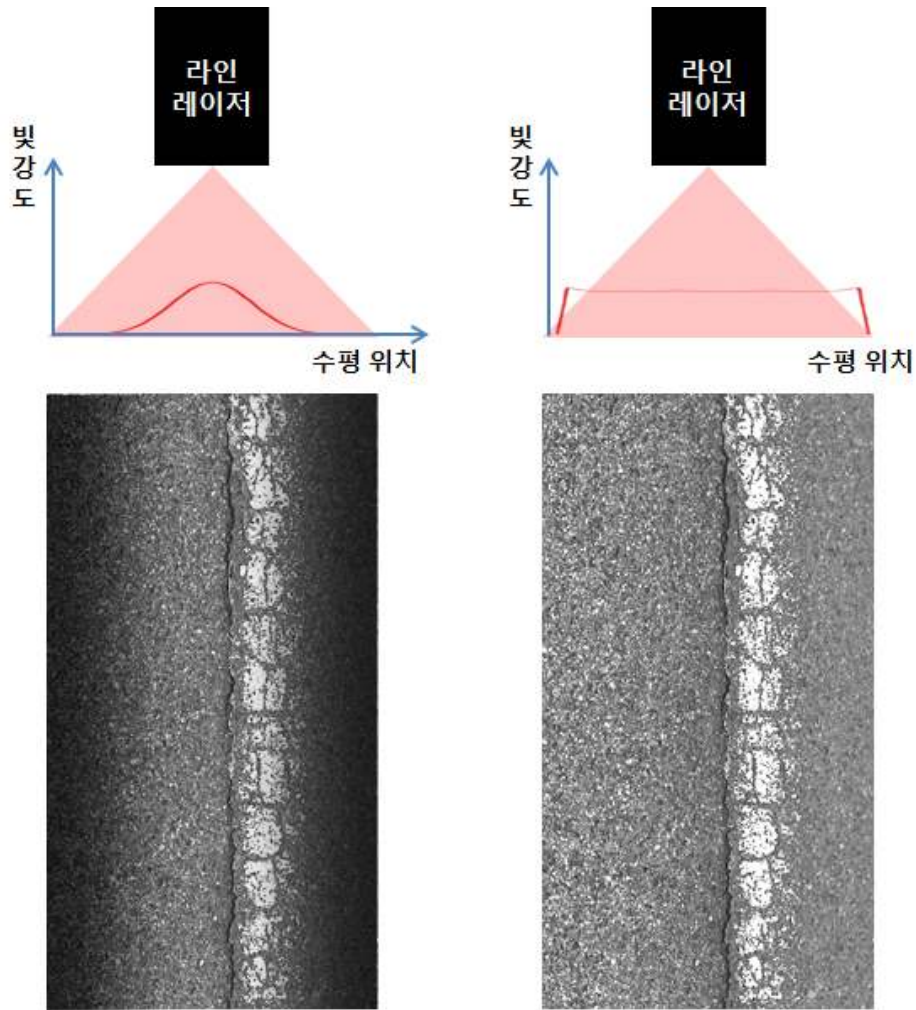


그림 3.10 라인레이저의 밝기 분포에 따른 획득 이미지
(좌: Gaussian 분포 / 우: Homogeneous 분포)

라인레이저의 파장대는 본 연구진에서 많은 노하우를 보유하고 있는 808nm의 파장으로 결정하였다. 표 3.1은 외부에서 가장 강한 광원인 태양광에서 사용할 레이저 사양을 비교 요약한 것이다.

표 3.1 적외선 라인레이저 사양 비교

구분	IR LineBeam System	LS-8010K-L90	ZQ-Laser
레이저 파장	808nm	808nm	808nm
레이저 밝기분포	Gaussian	Homogeneous	Homogeneous
라인굵기	8mm	≤2mm	≤1mm
외형			

위 라인레이저 중에서 레이저 밝기 분포가 Gaussian인 것은 제외하고 Homogeneous한 것 중에서 라인 폭이 가장 얇은 ZQ-LASER를 선정하여 본 연구에 적용하였다. 라인레이저의 방사각은 카메라의 스캔 폭 이상이 필요하므로 1.8m 거리에서 1.4m 이상의 라인 길이가 확보되는 43도 이상의 방사각을 확보하여야 한다. 계산상 최적의 방사 각은 45도 이지만, 라인레이저 양 끝단 측 라인의 균질성이 떨어지는 것을 고려하여 일반적인 상용 렌즈의 화각인 60도 렌즈를 적용하였다. 선정된 라인레이저의 세부 사양은 그림 3.11과 같다.

Output power	up to 6,000mW
Wavelength	808nm
Power stability	±1% over operating temperature range within 24h, ±5% over complete lifetime±1% over operating temperature range within 24h, ±5% over complete lifetime
Wavelength vs. temperature	Typ. ±1nm over operating temperature range
Pointing stability	< 15μrad / °C
Projection	line homogeneous, line flat top, dot circular, dot elliptical
Line homogeneous profile	10°, 20°, 30°, 45°, 60°, 75°, 90°
Point	Elliptical
Adjustable focus	yes
Focus range	50mm to 10,000mm
Divergence of beam FWHM	0.3mrad (1 / e²), 0.2mrad (FWHM)
Intensity control	yes

그림 3.11 적용 레이저 사양

라. 카메라와 레이저 테스트

선정된 카메라와 라인레이저를 이용하여 3차원 레이저 변위측정기 테스트 지그를 그림 3.12와 같이 구성하였으며 동작 테스트를 수행하였다. 그림 3.13은 실제 테스트 시 촬영된 고속카메라의 레이저라인을 나타낸 것이다.

(1) 테스트 조건

- 가) ROI 설정 : 2304 x 32
- 나) 적용화각 : 60도

(2) 테스트 결과

- 가) 촬영속도 : 23,000frame/sec
- 나) 영상 : 레이저 라인 확인
- 다) 분해능 : 약 4mm/pixel



그림 3.12 카메라와 라인레이저로 구성된
3차원 레이저 변위측정기



그림 3.13 고속 카메라로 촬영된 레이저라인

마. 주변광 차단필터 선정

차선상태를 조사하기 위해서는 태양과 같이 강한 외부광원에 노출된 환경 뿐 아니라 터널과 같이 인공조명 환경에서도 데이터 획득이 가능하여야 한다. 레이저 광원을 이용한 3차원 레이저 변위측정기의 경우 이러한 외부 광원의 영향을 배제하지 않으면, 주변광으로 인해 데이터의 신뢰도가 저하된다. 이러한 문제를 최소화하고 데이터 신뢰도를 확보하기 위해서는 그림 3.14 와 같이 주변광을 최대한 차단하여야 한다.

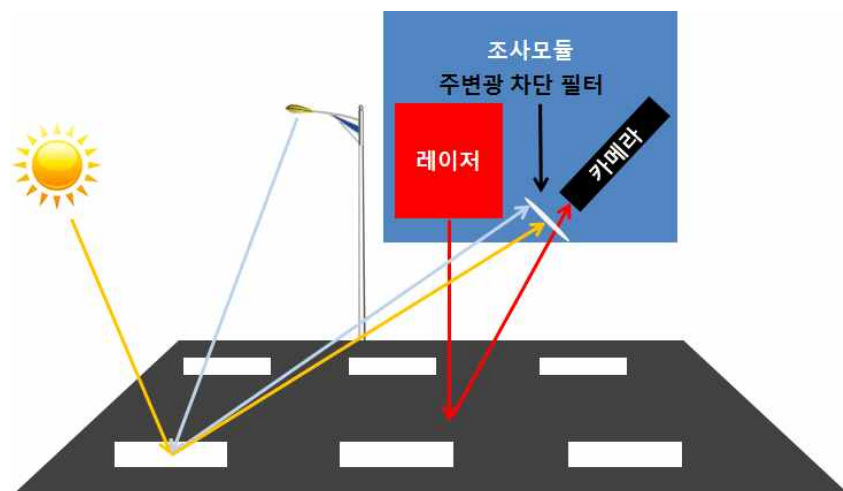


그림 3.14 차선도색 상태 측정기의 주변광 차단필터 역할

본 연구에서는 단일 파장인 808nm의 레이저 광원을 사용하였다. 따라서 808nm의 파장대만 통과시키는 밴드패스 필터(Band-Pass filter)를 구성함으로써 주변광을 제거할 수 있다. 태양광 속에도 808nm 파장대의 적외선이 존재하지만 이 파장대의 빛의 세기만을 비교해 보면 라인레이저에 비해 무시할 만한 수준이다. 본 과업에 적용될 필터와 그 사양은 그림 3.15 및 16과 같다.

- 필터 크기 : $\phi 25 * 0.55\text{mm}$
- 패스 파장 영역 : 808nm(FWHM, Full Width at Half Maximum : 20nm)
- 패스 영역 투과율 : 90% 이상

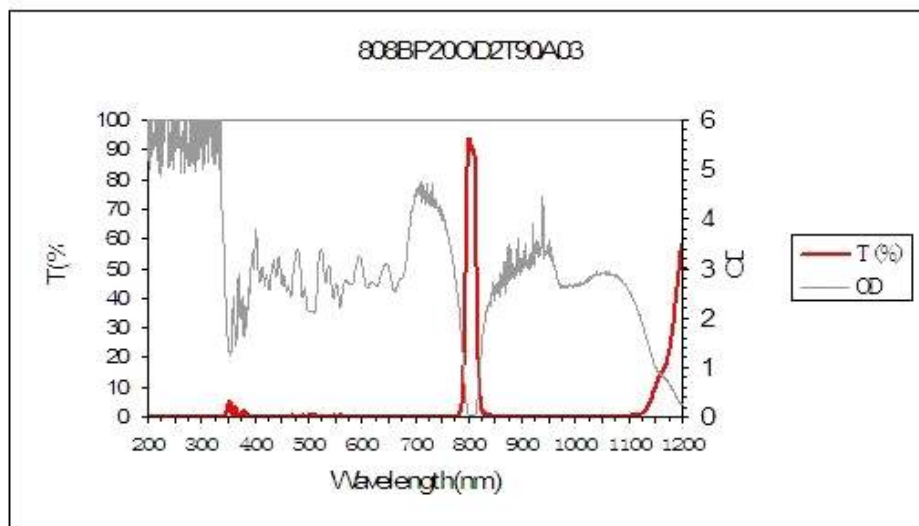


그림 3.15 밴드패스 필터 요구사양



그림 3.16 테스트에 사용된 필터 예

바. 카메라와 레이저 광원 간 간격설정

그림 3.17는 3차원 레이저 변위측정기를 구성할 때 카메라와 레이저 광원 간 간격과 데이터의 분해능 및 측정범위와의 관계를 도식화 한 것이다. 두 센서간의 거리가 감소할수록 측정범위(수직 깊이 방향)는 증가하는 반면, 분해능은 감소한다. 추가적인 영향으로는 두 센서의 사이 각이 줄어들면서 카메라가 검지 못하는 음영지역이 줄어 누락 데이터가 감소한다. 이와 반대로 두 센서간의 거리가 증가하게 되면, 분해능은 증가하는 반면 측정범위(수직 깊이 방향)는 감소한다. 추가적인 영향으로는 두 센서의 사이 각이 늘어나면서 카메라가 검지 못하는 음영지역이 늘고, 따라서 누락되는 데이터 또한 늘게 된다. 만약 측정범위를 고정한다고 가정하면 두 센서 간 간격이 바뀔 때마다 증감하는 측정범위의 크기만큼 측정 속도를 증감할 수도 있다. 본 과업에서는 0.5mm 수직 변위 분해능과 14,000frames/sec의 최대 조사속도를 확보하기 위해 센서 간격을 570mm로 설정하였다.

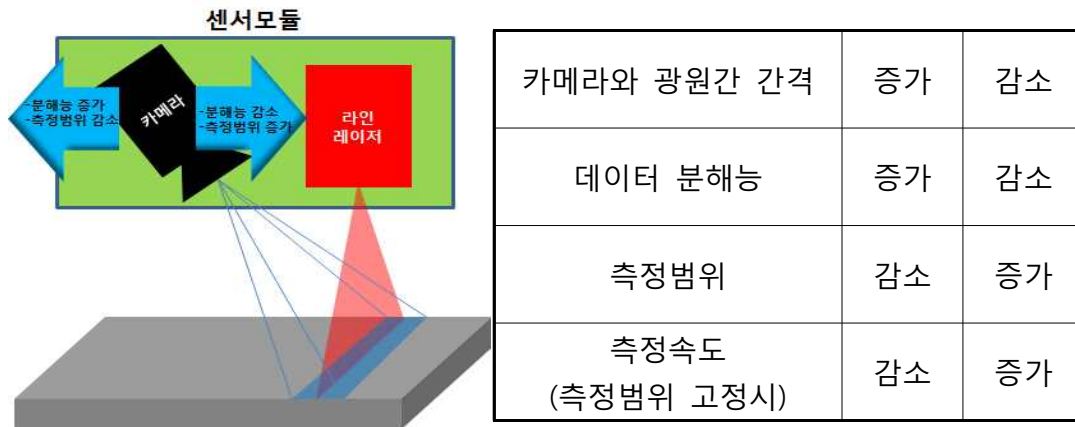


그림 3.17 카메라와 광원간의 거리에 따른 효과

사. 기구 제작 및 조립

선정된 카메라, 렌즈, 라인레이저 및 카메라와 라인레이저간 간격을 기반으로 기구 설계를 진행하였다. 그림 3.18~19와 같이 설계된 도면을 기반으로 정밀 CNC가공을 통하여 차선도색 상태측정기 시제품을 그림 3.20~21과 같이 조립하였다.

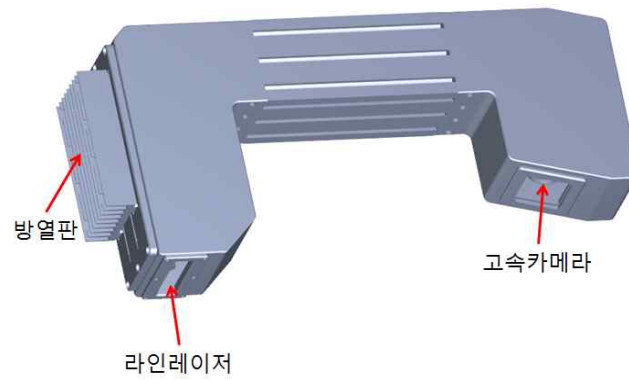


그림 3.20 차선도색 상태측정기 3차원 레이저
변위측정기조감도



그림 3.21 차선도색 상태측정기 시제품

아. 거리측정기(DMI, Distance Measurement Instrument) 사양 결정 및 제작

DMI는 거리기반 데이터 획득 시 반드시 필요한 장치이다. DMI는 정확한 거리를 측정할 수 있어야 하고, 정해진 간격마다 트리거 정보를 각 센서에 공급할 수 있어야 하며, 실시간 현재 거리를 모니터링 할 수 있어야 한다. 정확한 거리의 측정은 데이터 정확성 및 신뢰도 향상에도 기여한다. 개발할 DMI는 1mm 거리측정 분해능을 기반으로 총 8개의 독립 트리거를 제공할 수 있도록 표 3.2와 같이 설계하였다. 또한 다년간 도로 상태 조사를 한 경험을 바탕으로 추가적인 필요 기능(현재거리 캡취 기능, 구간 거리 측정 기능 등)을 구현하였다.

표 3.2 DMI 설계 사양

구분	사양	비고
거리 분해능	1mm	
트리거 출력 수	8	독립
엔코더 분해능	5000펄스/회전	
기능	-현재거리 캡취 -구간거리 측정 -가상조사 기능 -다양한 거리단위 지원 -PC인터페이스 지원(원격 조작)	
인터페이스	-랜 통신(원격 조작)	

제작된 DMI 외형 및 설계 회로도는 그림 3.22 및 3.23과 같다.



그림 3.22 거리측정기(DMI) 구성

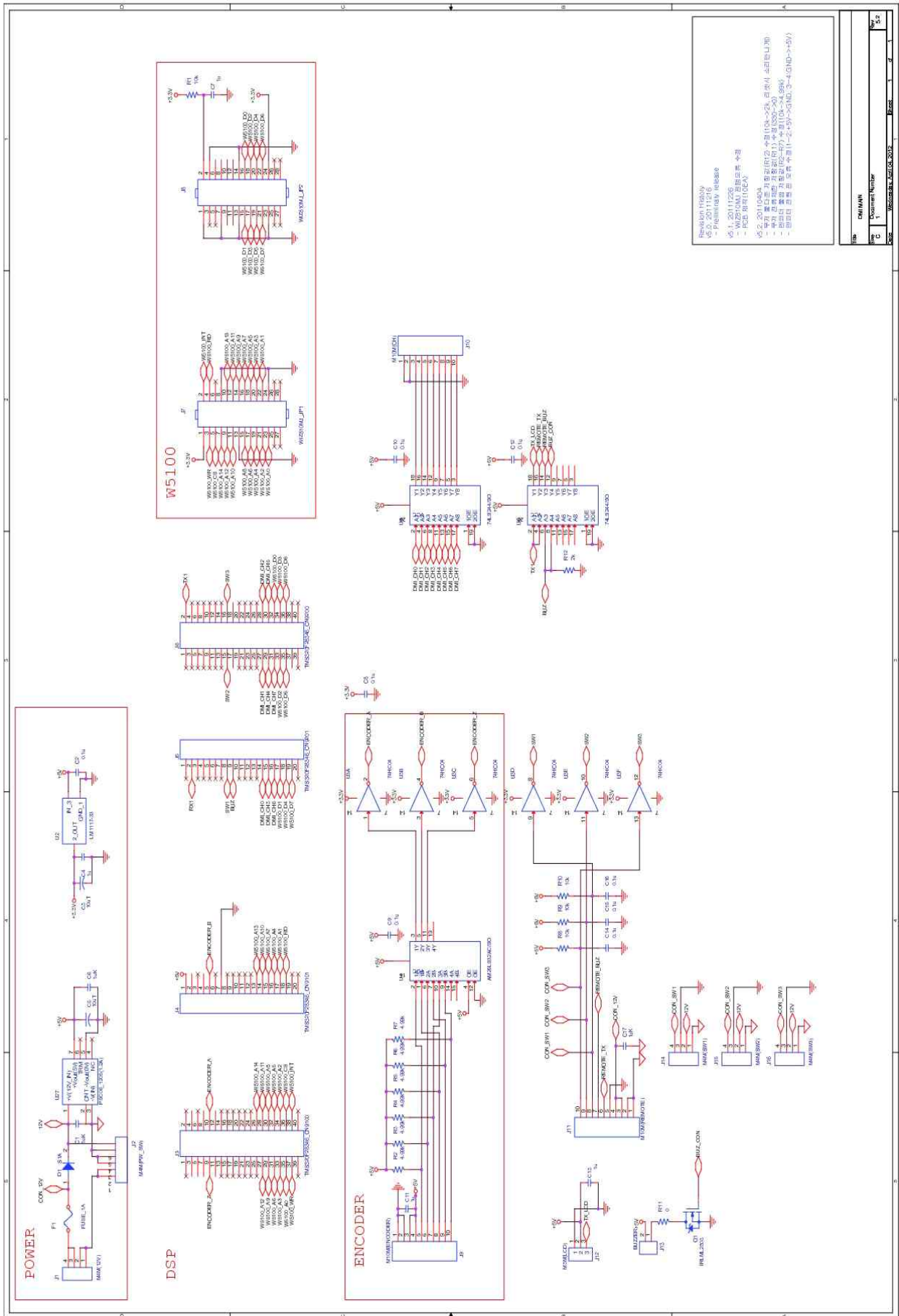


그림 3.23 DMI 회로도

DSP(Digital Signal Processor) 개발환경인 Code Composer Studio와 에뮬레이터를 이용하여 설계 사양을 만족하도록 펌웨어를 개발하여 그림 3.24와 같이 DMI를 완성하였다. 무엇보다 구현된 가상조사 기능을 사용하면 연결된 각 장치의 정상동작 여부를 이동 없이 확인할 수 있어, 실 조사 이전에 장비 상태 확인용으로 활용할 수 있다.



그림 3.24 DMI 펌웨어 개발

자. 라인추출 알고리즘 개발

라인레이저와 카메라 영상으로부터 3차원 변위데이터를 추출하는 일련의 과정은 그림 3.25와 같다. 획득된 라인영상으로부터 라인을 위치를 정확히 찾고 픽셀 정보와 캘리브레이션 팩터를 이용하여 실제 높낮이 정보로 환산한다. 이 때 이미지로부터 라인을 찾는 방법이 가장 중요하며 많은 시간을 필요로 한다.

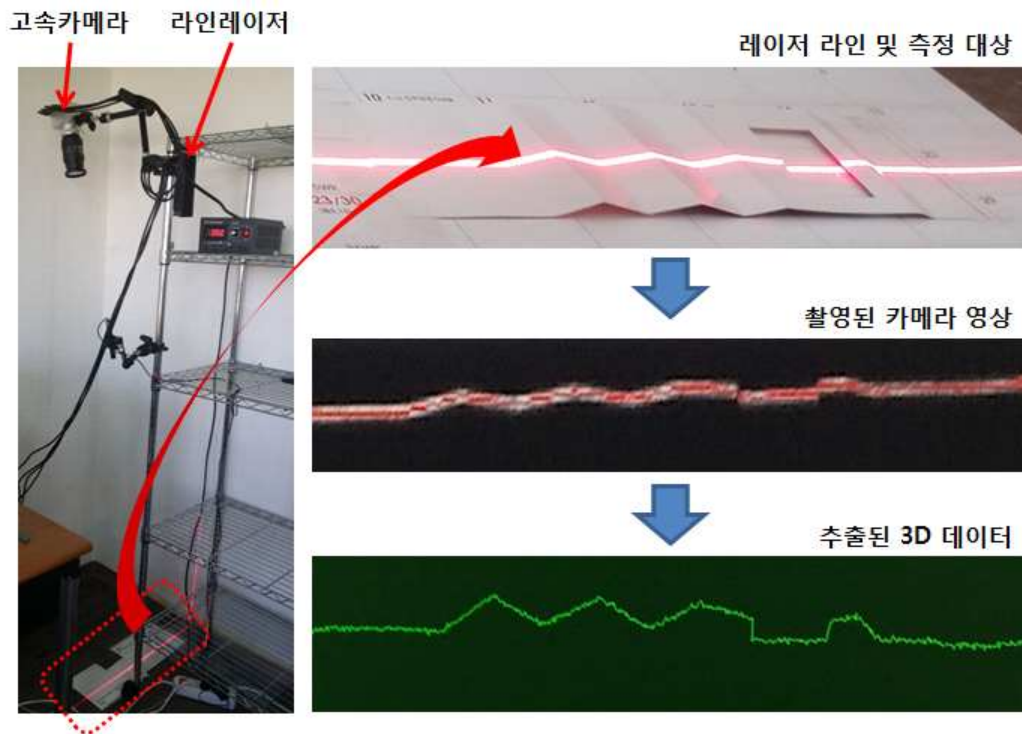


그림 3.25 라인레이저와 카메라로부터 3차원 변위데이터추출 과정

시속 100km/h의 속도로 주행하면서 2mm간격마다 3차원 변위데이터를 획득하기 위해서는 초당 13900frame의 영상을 처리하여 3차원 변위데이터로 변환하여야 한다. 이렇게 고속 연산을 수행하기 위해서는 속도가 빠르면서 정확도가 높은 이미지 프로세싱 알고리즘이 필요하다. 이뿐 아니라 이 모든 연산을 CPU가 아닌 하드웨어적으로 구현 하여 처리 속도를 증가시킬 수가 있다. 그 방법 중 하나가 알고리즘을 FPGA(Field Programmable Gate Array)에 구현하는 것이다. FPGA는 연산을 할 수 있는 하드웨어 게이트들을 모아놓은 칩으로 각종 알고리즘을 고속으로 구현할 수 있다. 본 연구에서는 고속 알고리즘을 구현하고 이를 FPGA에 구현하고 원하는 성능을 확보하였다.

라인 추출에 사용한 알고리즘은 AQSense의 “Peak Detector”란 알고리즘으로 두꺼운 레이저 라인 주 가장 밝은 부분을 라인의 위치라고 판단하는 알고리즘이다. 이 알고리즘을 커스터마이징하여 그림 3.26과 같이 FPGA에 구현함으로써 목표 성능을 구현하였다.

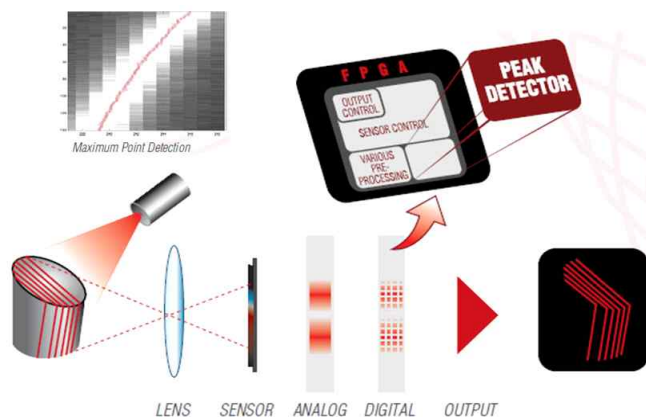


그림 3.26 Peak Detector 알고리즘 및 실시간 처리를 위한 FPGA 탑재

차. 조사프로그램 개발

조사 프로그램은 각 센서를 제어하여 조사를 수행하고, 센서로부터 수집된 데이터를 저장하는 기능을 한다. 조사정보창에서는 조사에 필요한 제반 정보를 설정하고 각 센서의 상태를 모니터링한다. 표면창에서는 실시간 획득되는 3차원 변위데이터 중 노면 영상을 표출해 준다. 현황창에서는 실시간 촬영된 도로의 주변영상을 보여준다. 분석 시에 조사 위치 파악을 위해 GPS궤적 정보를 거리와 연동하여 저장하는 기능 또한 구현하였다. 개발된 조사프로그램의 화면 구성은 그림 3.27과 같으며, 조사프로그램의 개발 사양은 표 3.3과 같다.

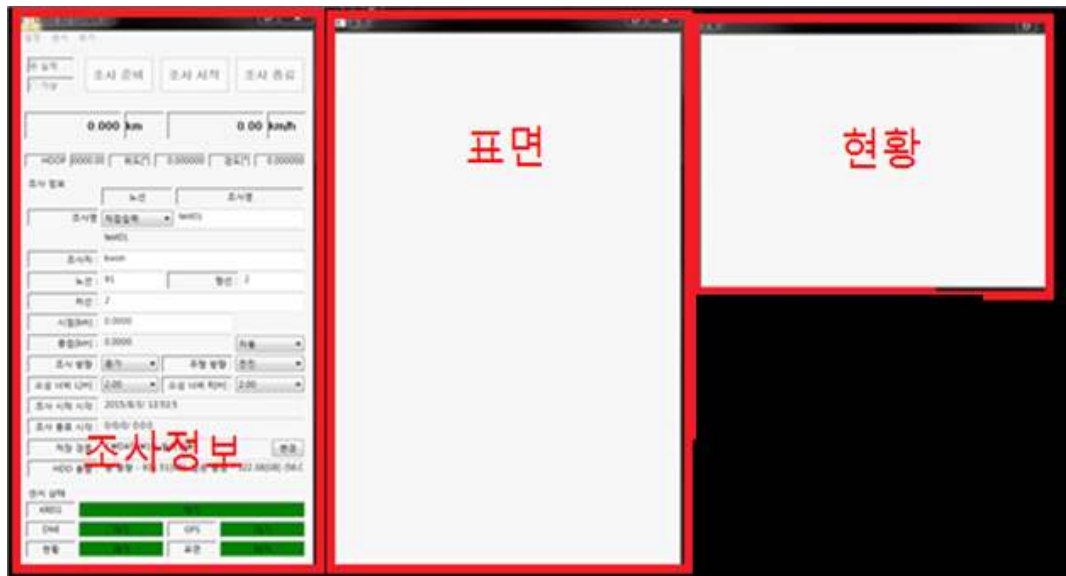


그림 3.27 조사프로그램 창 구성

표 3.3 차선도색 상태측정기 조사프로그램 개발 사양

구분	사양	비고
조사항목	-차선상태(3차원 변위데이터) -현황(360도 전방위 영상) -GPS	선택적 취득 가능
기능	-각 센서 상태 모니터 -각 센서 데이터 누락 체크 -한계 조사속도 알림	

조사를 제어하는 버튼은 세 개로 구성하여 조사 편의를 극대화하였다. 프로그램의 조사 시 동작화면은 그림 3.28과 같다.



그림 3.28 차선도색 상태측정기 조사프로그램 조사 화면

그림 3.29는 상태 측정기 캘리브레이션 지그 및 프로그램을 나타낸다.

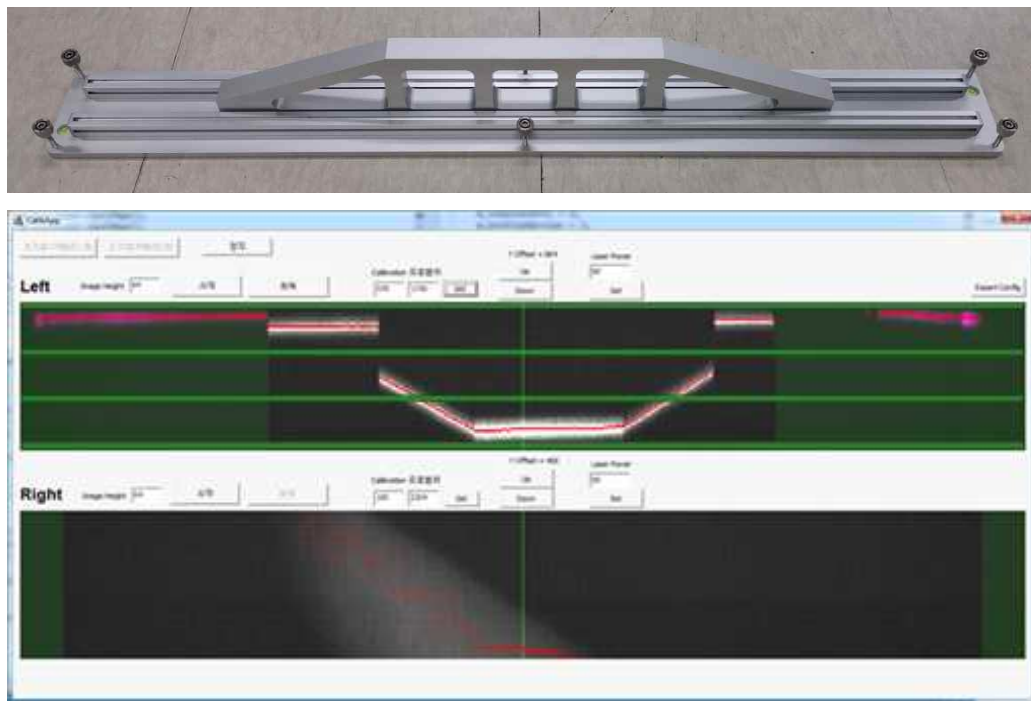


그림 3.29 상태 측정기 캘리브레이션 지그 및 프로그램

캘리브레이션 지그를 이용한 캘리브레이션 방법은 다음과 같다.

- (1) 그림 3.29의 프로그램을 실행한다.
- (2) 초기화(카메라 1개)버튼을 누르고 시작버튼이 활성화 될 때까지 기다린다.
- (3) 시작버튼을 누르면 레이저가 나오면서 뷰 창에 카메라가 촬영 중인 화면이 나온다.

- (4) 만약 화면의 녹색 수평선과 레이저가 맞지 않으면 카메라를 조절하여 수평을 맞춘다.
- (5) 캘리브레이션 지그를 넣어 레이저가 지그 세로 폭 가운데 오게 맞춘다.
- (6) 뷰 창외 가운데 초록색 세로 줄 위치에 캘리브레이션 지그가 중앙에 오도록 맞춘다.
- (7) 다 맞췄으면 레이저를 끄고, 캘리브레이션 지그 위에 수평계를 놓고 캘리브레이션 지그의 수평을 맞춘다.
- (8) 다시 레이저를 켜고, Image Height 값을 변경해서 view창에 캘리브레이션 지그의 상하단이 모두 나오도록 설정한다. Y Offset의 위아래 버튼을 이용하여 지그가 최대한 가운데 오게 조정한다.
- (9) 캘리브레이션 옵션은 캘리브레이션 지그의 좌우 끝단 안쪽으로 오도록 조절한다.
- (10) Laser Power를 조절하는데 이때 너무 강하면 Profile 선이 두꺼워지고, 반대로 너무 약하면 Noise가 많아지니 화면을 보고 알맞게 맞춰준다.
- (11) 취득 버튼을 눌러 “profile_single_left.json” 파일을 생성한다.
- (12) 그 다음 ProfileCalibrationTool 프로그램을 실행한다.
- (13) 그림 3.30의 빨간색 박스와 같이 설정하고, Open Jig Profile 버튼을 눌러 앞서 생성된 json파일을 선택한다.

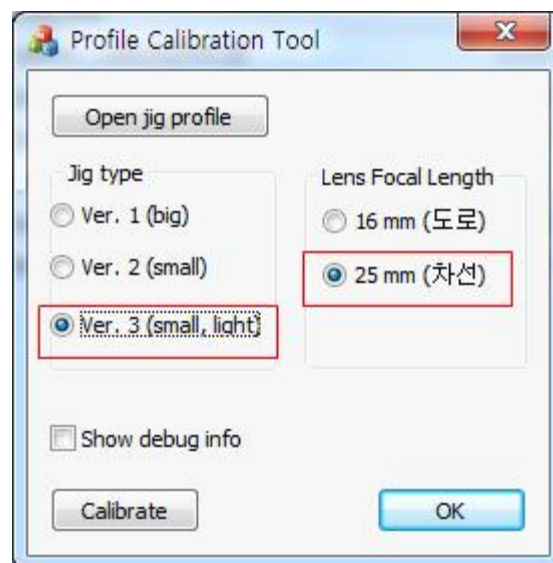


그림 3.30 상태 측정기 캘리브레이션

- (14) Calibrate 버튼을 누르면 calibration_left.json 파일이 실행파일과 같은 폴더 내에 생성된다.
- (15) 그 다음 생성된 json 파일을 조사프로그램 하위에 있는 NoviRSJson 폴더에 복사해준다. (이때 만일을 대비하여 기존 파일들은 전부 백업해둔다.)

카. 성능 테스트

(1) 실내테스트

개발 센서의 차량장착 전 성능 확인을 위해 그림 3.31과 같이 실제 설치높이를 시뮬레이션 할 수 있는 거치대를 제작하여 임시 장착하여 성능테스트를 시행하였다. 앞서 서술한 것과 같이 승합차량 혹은 RV 차량 후방 상부에 장착되는 가정 하에 센서의 장착 높이는 1800mm 가 되도록 설계하였다.

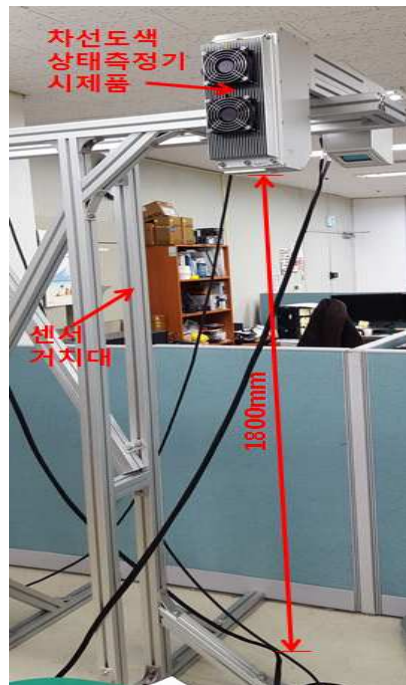


그림 3.31 실내 테스트

(가) 조사 속도 및 측정 속도 테스트

- 조사간격 : 2mm
- 조사속도 : 100km/h(가상조사)
- 조사거리 : 10km 내외(가상조사)
- 테스트 방법 : DMI의 가상조사 기능을 이용하여 시속 100km/h의 조사 후 (13,889회/초)로 데이터를 획득한 후 데이터 누락 확인

측정 속도 테스트 결과, 100km/h의 속도(13,889회/초)에서 데이터 누락 없이 고속으로 3차원 변위 형상자료가 수집됨을 확인하였으며 시험 결과를 표 3.4~3.5에 정리하였다.

표 3.4 조사 속도 및 측정 속도 테스트 결과

테스트 횟수	조사 거리[km]	조사속도 [km/h]	측정속도 [회/초]	데이터 누락 개수
1	10.112	100km/h	13,889	0
2	9.890	100km/h	13,889	0
3	10.325	100km/h	13,889	0
4	10.219	100km/h	13,889	0
5	10.101	100km/h	13,889	0
6	10.406	100km/h	13,889	0
7	10.098	100km/h	13,889	0
8	10.070	100km/h	13,889	0
9	10.109	100km/h	13,889	0
10	10.207	100km/h	13,889	0

표 3.5 개발 시제품 목표성능

항목	목표치	달성치	달성율
속도	100km/h	100km/h	100%
SAMPLE RATE	13,889회/초	13,889회/초	100%

(나) 수직 분해능 테스트

① 1차 테스트

- 조사간격 : 1mm
- 조사속도 : 80km/h(가상조사)
- 조사거리 : 100m 내외
- 테스트 방법 : 크기를 알고 있는 기준 블록을 바닥에 놓고 측정하여 실제값과 비교

기준 블록은 그림 3.32와 같이 별도의 정밀 가공을 통해 5~22mm의 다양한 크기를 갖도록 제작 하였고, 실제높이와 개발된 센서에서 취득되는 높이를 비교하였다. 시험 결과 수직방향으로 0.5mm의 분해능 및 측정 오차를 확인하였으며 테스트 모습 및 결과값은 그림 3.33 및 표 3.6과 같다.

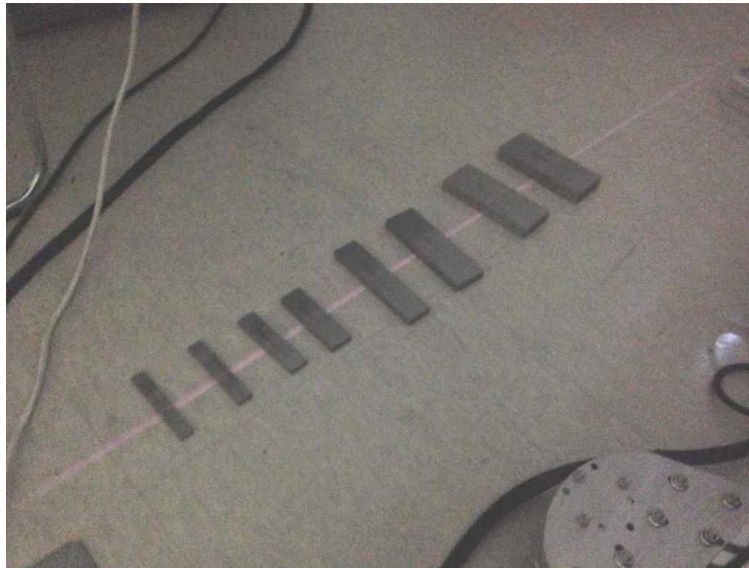


그림 3.32 기준 블록 조사

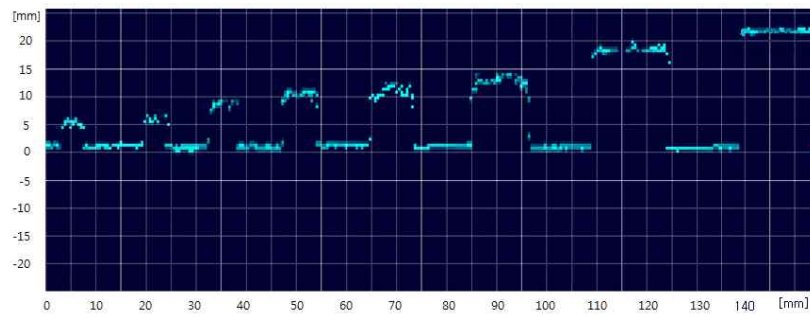


그림 3.33 높이 측정 값

표 3.6. 높이 측정 결과

블록 높이 [mm]	측정값 [mm]	오차 [mm]
5	5	0
6	5.5	0.5
8	8	0
10	10	0
12	12	0
14	13.5	0.5
18	17.5	0.5
22	22	0

② 2차 테스트

변위 산출 알고리즘을 개선하고 다양한 높이(5~50mm)의 기준 블록을 제작하여 외부환경에서도 정확한 수직 변위를 측정할 수 있는지 확인하기 위한 테스트를 그림 3.34와 같이 수행하였다. 테스트 결과 최대 0.4mm의 측정 오차를 확인하였다.



그림 3.34 차선도색 두께 측정 정확도 검증

표 3.7 두께 측정 정확도

블록 높이 [mm]	측정값 [mm]	오차 [mm]
5.0	5.0	0.0
9.9	10.1	0.2
14.9	14.9	0.0
20.0	20.0	0.0
30.2	30.2	0.0
50.0	49.6	0.4

(다) 스캔 폭 테스트

- 조사간격 : 1mm
- 조사속도 : 80km/h(가상조사)
- 조사거리 : 100m 내외
- 방법 : 가상조사 화면에서 기준 블록이 조사화면에서 확인되는 각 위치에 위치시키고 기준블록간 거리 실측

스캔 폭 테스트 결과 1.5m 정도의 폭을 스캔하며 목표치인 50cm 이상을 스캔함을 확인하였다.

(2) 실외테스트

가로 및 세로 분해능 확인과 주야간 조사를 테스트하기 위해 센서를 수행사가 보유하고 있는 조사차량에 임시고정 후 테스트를 실시하였다. 실제 포장노면의 환경조건을 최대한 반영하기 위하여 별도의 기준 물체를 설치하는 방식이 아닌 도로포장에 발생된 균열폭을 육안으로 실측하여 개발장비에서 취득된 영상에서 균열폭 확인 여부를 비교하는 방식으로 진행 하였다.

(가) 가로 및 세로 분해능 테스트

- 조사간격 : 1mm
- 조사속도 : 20km/h 내외
- 조사거리 : 100m 내외
- 방 법 : 도로상의 균열을 측정한 뒤 실측을 통해 균열 두께를 측정하고, 조사된 데이터 상에서 식별 가능한 균열 폭 확인

그림 3.35와 같이 1mm 간격 조사 데이터에서 가로 및 세로 분해능 확인 1mm이하까지 식별 가능함을 확인하였다.

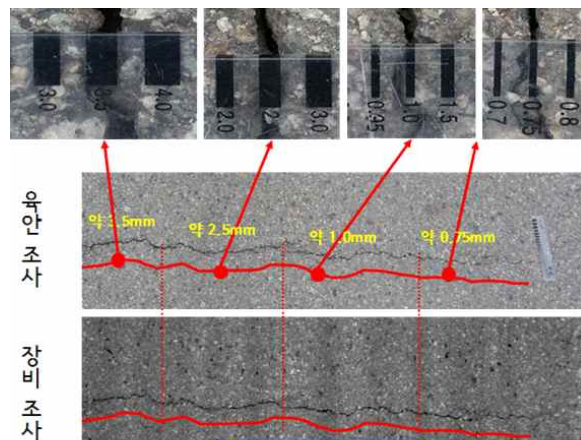


그림 3.35 장비 조사와 육안조사의 분해능 비교

(나) 측정조건 테스트

- 조사간격 : 1mm
- 조사속도 : 70~80km 내외
- 조사거리 : 1km 내외
- 방법 : 동일 지역을 주간과 야간에 조사하여 데이터 간 차이를 비교

외부광원의 효과적인 차단 및 주야간 취득 데이터의 균질성을 확인하기 위해 주간 및 야간에 동일 지역 조사 데이터를 비교해본 결과 그림 3.36과 같이 주야간 환경에 영향을 받지 않고 조사됨을 확인하였다.

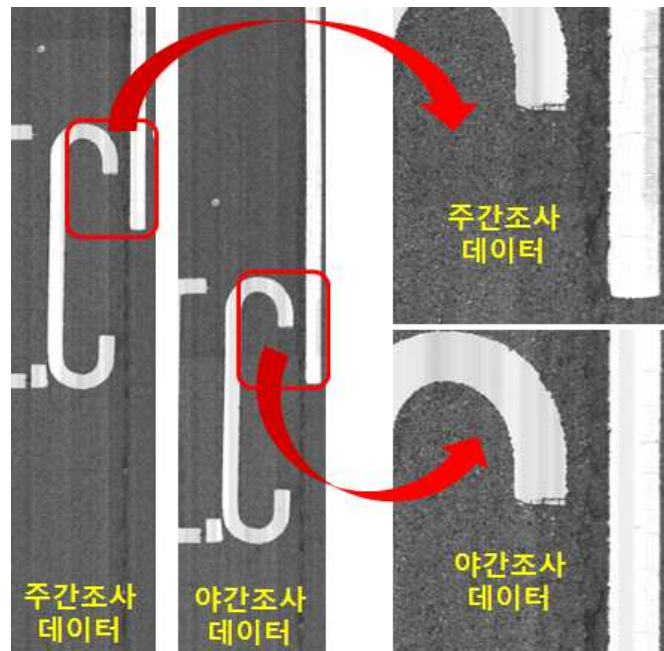


그림 3.36 주야간 조사 데이터

(다) 조사 궤적 테스트

- 위 치 : 해안로(경기도 안산시)
- 조사간격 : 0.1초
- 조사속도 : 70~80km/h 내외
- 조사거리 : 1km 내외
- 방 법 : 조사 궤적을 웹GIS맵상에 띄워 조사위치 확인

GPS데이터 취득 기능을 그 정확성을 확인하기 위해 안산시 소재 도로를 실제 주행하고 웹 GIS맵을 활용하여 확인해 보았다. GPS 데이터 형식은 NMEA(National Marine Electronics Association)형식을 사용하였다. 수집된 데이터를 상용 웹GIS맵(Google지도, 다음지도) 상에 표출해본 결과 그림 3.37과 같이 조사 위치 측정에 지장이 없음을 확인하였다.

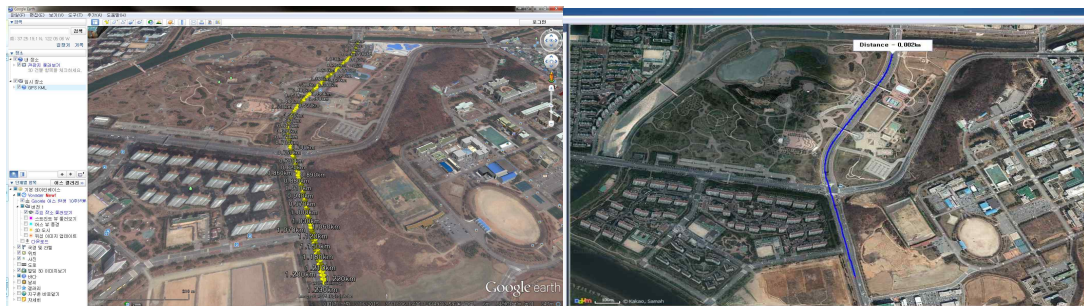


그림 3.37 웹GIS맵상에 조사궤적 표출

(라) 주변 현황 영상 수집 테스트

- 조사간격 : 10m
- 조사속도 : 80~90km/h 내외
- 조사거리 : 3km 내외
- 방 법 : 360도 전방위 영상 취득

360도 전방위 카메라를 이용하면 한 대의 카메라로 모든 방향의 이미지 데이터를 수집할 수 있다. 차선도색 상태측정기와 같이 협소한 시야각을 가진 센서로 조사할 경우 주변 상황 파악이 어려운 문제가 있다. 이를 해결하기 위해 360도 전방위 영상을 이용하면 그림 3.38처럼 넓은 시야각을 통한 주변 상황 파악을 용이하게 할 수 있다.



그림 3.38 360도 전방위 영상

(마) 차선 탈리량 정확도 테스트

- 조사간격 : 1mm
- 조사속도 : 0~30km/h 내외
- 조사거리 : 40m
- 방 법 : 임의 모양의 탈리 모형을 차선에 표기 후, 장비 측정 결과 비교

탈리량 측정 정확도 테스트를 위해 그림 3.39와 같은 샘플 지그를 제작하였다. 1m 길이의 차선 두 개에 면적을 알고 있는 마스킹 테이프를 이용하여 임의 모양의 탈리 형태를 붙여넣어 샘플 지그 2개를 제작하였다. 이를 이용하여 차선도색 상태 측정기의 탈리량 측정 정확도를 그림 3.40과 같이 확인하였다.

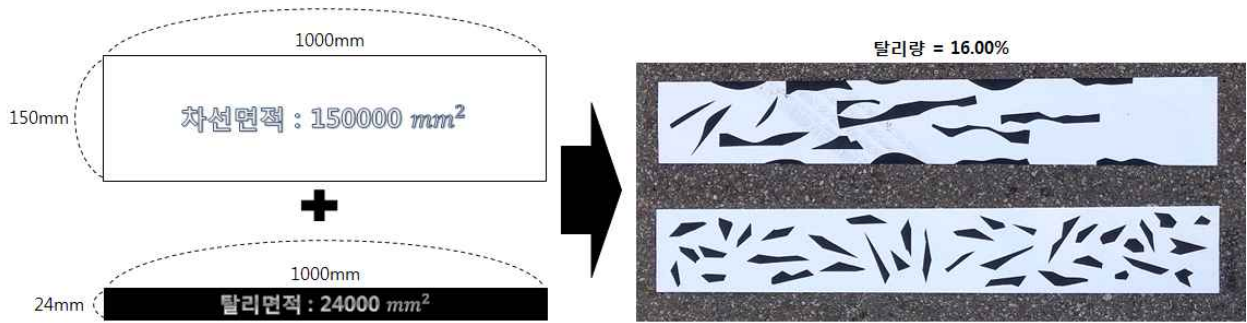


그림 3.39 탈리량 샘플 제작



그림 3.40 탈리량 정확도 테스트

그림 3.41은 탈리량 측정 정확도 테스트 결과를 나타낸 것이다. 임의 모양의 탈리 모형대로 탈리량이 검측된 것을 알 수 있으며, 표 3.8과 같이 제작된 차선도색 상태 측정기는 5% 이내의 정확도로 탈리량을 측정함을 확인하였다.

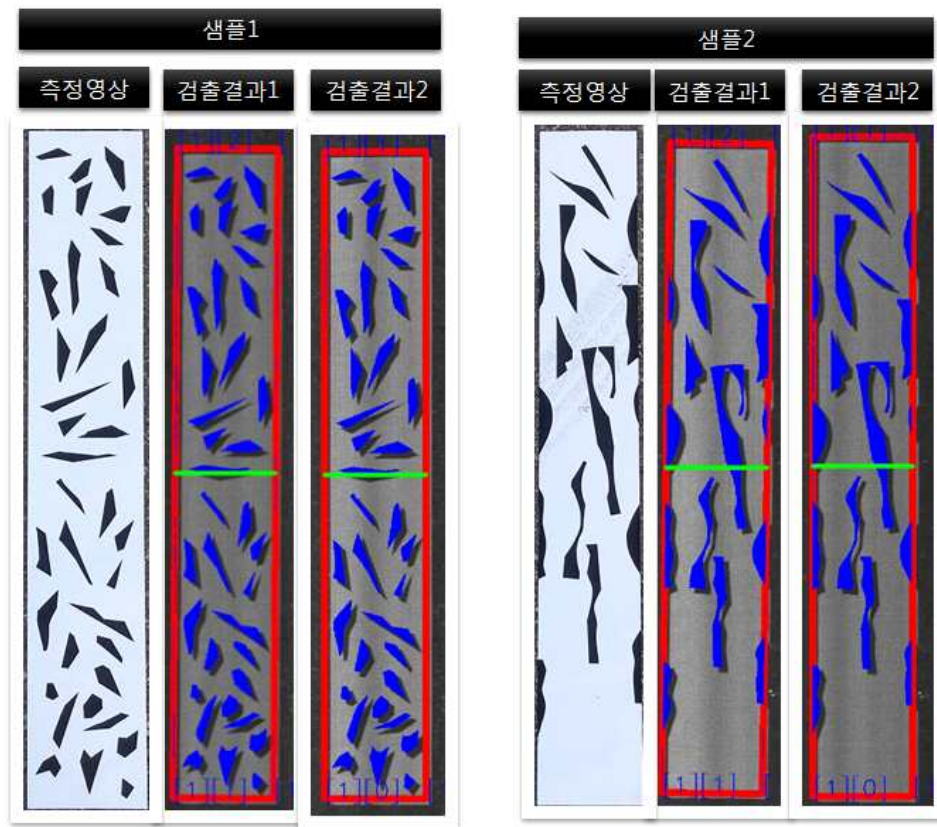


그림 3.41 탈리량 검출 결과

표 3.8 탈리량 측정 정확도(샘플1)

샘플	측정횟수	측정 탈리량[%]	기준 탈리량[%]	오차[%]
샘플1	1	16.37	16.00	2.31
	2	15.92	16.00	0.50
샘플2	1	15.33	16.00	4.18
	2	16.17	16.00	1.06

(바) 차선 두께 정확도 테스트

- 조사간격 : 1mm
- 조사속도 : 0~30km/h 내외
- 조사거리 : 40m
- 방법 : 교통량이 없는 샘플 차선 구간을 정하고, 그림 3.42와 같이 인력으로 차선 두께를 측정할 수 있는 장비를 이용하여 샘플 구간의 두께를 실측한 후 장비 측정값과 비교

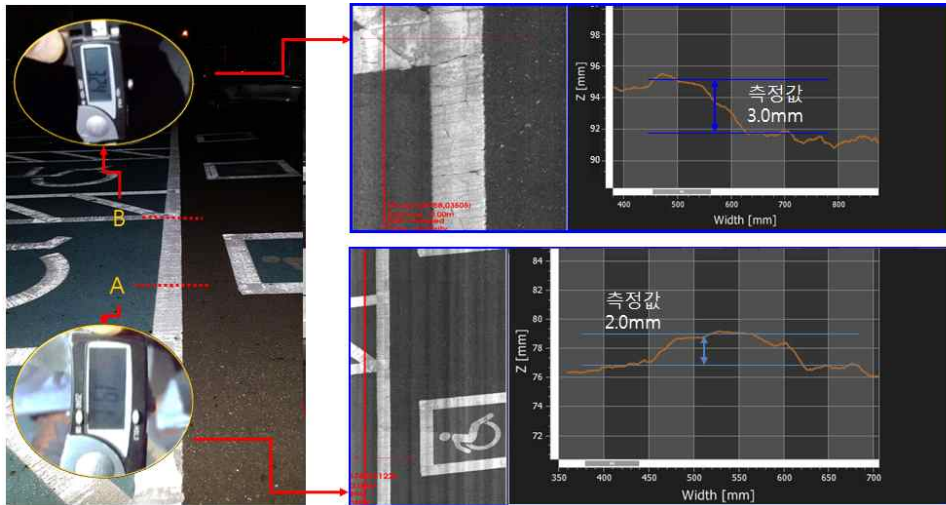


그림 3.42 차선 두께 측정 결과

제작된 차선도색 상태 측정기는 표 3.9의 시험결과와 같이 현장 실측값 대비 7% 이내의 정확도로 차선 두께를 측정함을 확인하였다.

표 3.9 차선 두께 정확도

측정횟수	측정값[mm]	실측값[mm]	오차[%]
1	3.0	3.2	6.3%
2	2.0	1.9	5.2%

타. 현장시험

차선 휘도 측정과 관련하여 장기적인 외산장비 운영 및 현장조사 경험이 있는 한국도로공사 담당자와 공동으로 고속도로 실제 현장과 동일한 환경조건을 갖춘 고속도로 시험도로에서 교통 차단 후 현장시험을 수행하였다. 그림 3.43은 현장시험 전경을 나타낸 것이다.



그림 3.43 두께 및 탈리량 현장 시험

(1) 차선도색 두께 및 탈리량 테스트

- 조사간격 : 1mm
- 조사속도 : 0~70km/h
- 조사거리 : 500m

도로공사 시험도로에서 500m 구간을 테스트 사이트로 선정하고, 두께값과 탈리량을 측정하였다. 그 결과 그림 3.44 및 3.45와 같이 약 1mm~3.5mm 정도의 두께 분포와 최대 8.5%의 탈리량이 검출되었다.



그림 3.44 차선 두께 측정 결과



그림 3.45 차선 탈리량 측정 결과

2. 차선도색재귀반사휘도측정기 개발

가. 국외 장비 기술 분석

(1) 외산 재귀반사휘도측정기 기술동향 분석

장비개발에 앞서 국내외에서 가장 많이 사용되는 외산장비 3종에 대해 성능을 조사하여 표 3.10에 정리하였다. 조사결과 재귀반사휘도 측정면에서는 유사한 성능을 보였으며, 사용광원이 나 무게등에서 차이가 있었다.

표 3.10 외산 휘도 측정기 비교

구분	LTL-M	ZDR-6020	LaserLUX
광원	백색광	백색광	레이저
측정너비	1000 x 1000 mm	1000 x 880 mm	1100mm
측정범위 (mcd/m ² /lux)	40 ~ 2000	0 ~ 4000	5 ~ 4000
무게	12.5kg	10.5kg	22kg
최고조사속도	90km/h	150km/h	96km/h
외형			

(2) 카메라형 휘도계 테스트

장비제작에 앞서 카메라로 휘도 측정이 가능한지 확인이 필요하다. 프랑스 ENTPE 사에는 DSLR에서 촬영한 이미지를 이용하여 휘도 분포도와 휘도값으로 변환하는 프로그램(Photolux)을 개발하였으며 현재 3.2버전까지 배포되어 사용되고 있다. 이 프로그램은 Luminance map의 원하는 면을 지정하여 평균 휘도값을 알 수 있도록 하고 있다. DSLR 이미지를 이용하여 절대 휘도값을 얻기 위해서는 하드웨어적인 보정작업이 필요하며, 이 작업을 생략하면 상대적인 휘도값을 얻을 수 있다.

현재 PhotoLux의 모바일용 버전이 공개되어 있어 이를 이용하여 도로 차선의 상대 휘도값을 측정하였다. 그 결과 그림 3.46과 같이 주변 상황에 따라 동일 지역에 대해서도 상대 휘도는 다른값으로 측정됨을 알 수 있다.

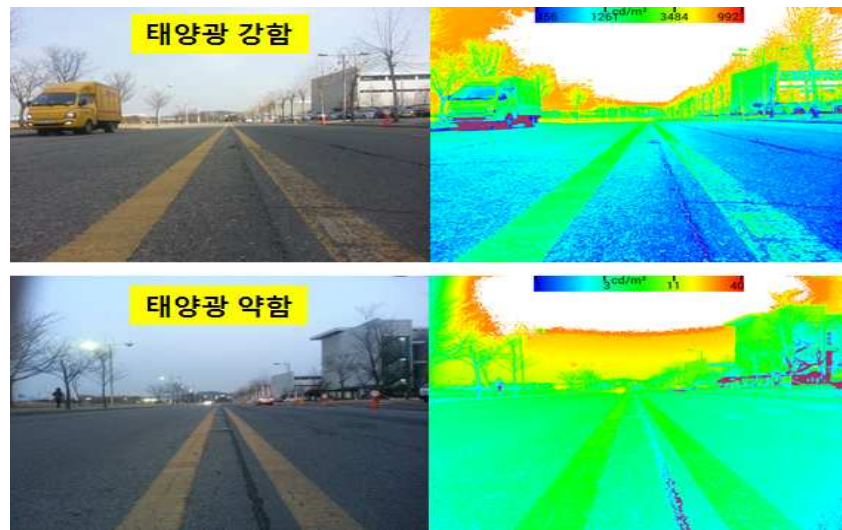


그림 3.46 일반카메라를 이용한 상대 휘도 측정

(3) 국내 도입 제품 운용실무자 의견 수렴

한국도로공사에서는 재귀반사휘도 측정기를 도입하여 운용하고 있다. 장비 개발에 있어 시행착오를 줄이고 운용실무자가 필요로 하는 기능을 포함시키기 위해 운용실무자의 의견을 수렴하였다. 도로공사에 도입된 두 장비를 비교해보면 표 3.11과 같다.

표 3.11 외산 휘도 측정기 비교

구분		LaserLux	LTL-M
광원		레이저	백색광
Calibration	지그개수	2개	1개
	필요회수	2회(황색 1회, 백색 1회)	1회(구분없음)
조사 시 차선색 구분		수동	자동
휘도분석 간격설정		조사 전에 미리 설정	조사 후에 변경가능
실무자 의견		캘리브레이션 불편	캘리브레이션 용이
실물사진			

네 번의 협의 과정을 거쳐 취합된 운용 실무자의 의견은 표 3.12와 같으며 이를 수렴하여 개발 목표 사항에 추가하였다.

표 3.12 장비 운용 실무자 의견사항

실무자 의견	목표 반영 내역
재귀반사 휘도뿐 아니라 야간의 차선 휘도 측정기능도 필요함	기술적으로 문제가 없으면 반영하도록 함
측정 지점의 거리가 짧을수록 운용 용이	기하학적 각도를 유지할 경우 측정지점의 거리를 줄이는 것은 불가능함 만약 기하학적 각도를 유지하지 않고도 측정이 가능하면 반영 가능함(테스트 필요)
저속 조사시 GPS값이 중첩되어 데이터에 문제가 발생함	데이터를 DME거리기반으로 정렬하고 관리하면 이 문제를 해결할 수 있음
조사 정확도가 조사속도에 영향을 받지 않아야 함	조사속도에 무관하게 조사 정확도가 유지될 수 있도록 거리기반 데이터 수집 및 분석 수행
동일한 차선이라도 속도별 사용자 느낌이 다를 수 있어 속도별 상태 지수를 개발할 필요가 있음	본 연구과제와 상관관계가 적어 추후 새로운 연구과제로 진행해볼 필요가 있음
캘리브레이션 절차 간소화	캘리브레이션 절차를 최소화하여 사용자 편의성을 극대화할 수 있도록 개발 방향 설정

운용실무자의 의견 중 레이저 방식보다는 백색광 방식이 캘리브레이션에 대해 편리한 측면의 의견을 제시하였으며, 이에 본 연구에서는 백색광 조명의 적용에 대해 기술적인 검토를 수행하였다.

나. 광원 선정

(1) 백색광원 사용 테스트 및 주변광 영향제거 방법

재귀반사휘도 측정을 위해서는 주변광의 제거가 필수적이다. 하지만 백색광은 여러 파장의 빛이 공존하므로 하드웨어적인 필터링이 불가능하다. 따라서 소프트웨어적인 필터링 방법이 필요하다. 소프트웨어적 필터링의 방법으로 평상시 영상과 백색광원 점등시 영상을 얻고 두 영상의 차를 구하여 백색광원 성분만을 추출하는 방법을 고안하였다. 해당 방법으로 성능 확인을 위해 그림 3.47과 같이 테스트를 실시하였다.

- 노출시간 : 1/60초
- 조리개 : F4.0
- ISO : 100

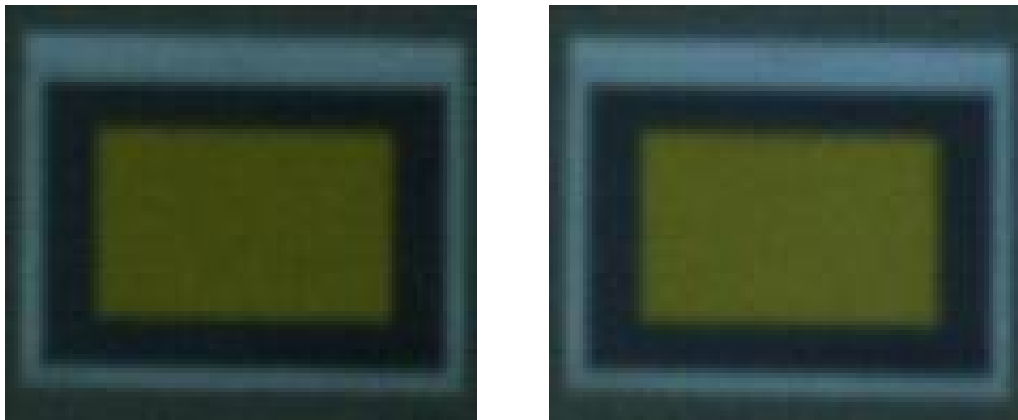


그림 3.47 밝기 실내 테스트 예 (좌:소등, 우:점등시)

실내 테스트 결과 영상 차를 이용한 주변광(형광등) 제거 및 백색광원 성분을 추출하였고 실외환경에서 테스트를 실시하였다.

- 노출시간 : 1/1200초
- 조리개 : F16.0
- ISO : 100

그림 3.48은 백색광원 추가여부에 따른 시험 결과를 비교한 것이다. 테스트 결과 주변광(태양광)의 영향이 너무 커서 광원을 점등했을 때와 소등하였을 때 영상의 밝기 차이가 나지 않아 주변광(태양광) 제거가 불가능 하였다. 테스트 결과로 이 방식의 필터링 방법은 태양광 제거에 부적합하다고 판단된다. 따라서 백색광을 사용하기 위해서는 추가적인 주변광 필터링 기법에 대한 연구가 필요할 것으로 판단되며, 본 연구에서는 초기 설정 방식인 레이저 조명과 밴드패스 필터를 이용한 주변광 제거 기술을 적용하도록 설정하였다.

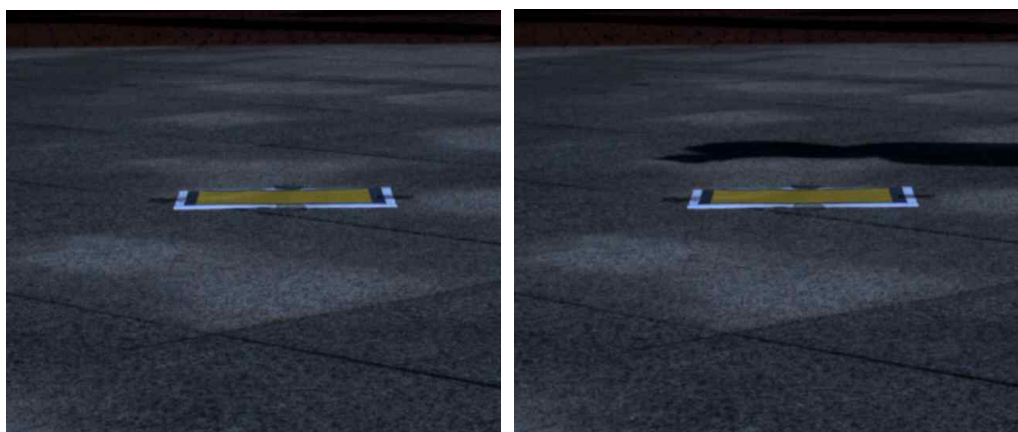


그림 3.48 외부광원 조건에서 추가 백색광원에 따른 색상변화
(좌,태양광, 우:태양광+백색광)

(2) 레이저 광원 조사 및 선정

레이저 광원의 종류는 크게 라인 레이저 타입과 포인트 레이저 타입으로 나뉘는데 라인 레이저는 표 3.13에 비교를 해 보았다.

표 3.13 라인레이저 사양 비교

구분	IR Line Beam System	LS-8010K-L90	ZQ-Laser
레이저 파장	808nm	808nm	808nm
레이저 출력	15w(가변조절기능)	10w(가변조정기능)	6w(가변조절기능)
레이저 밝기 분포	Gaussian	Homogeneous	Homogeneous
라인 폭	8mm	≤ 2mm	≤ 1mm
외형			

포인트 레이저는 1.1m의 폭을 조사하기 위해 회전판과 같은 부수적인 기구물이 필요하므로 내구성 측면에서 유리한 라인레이저 방식을 사용하기로 결정하였다. 레이저 광원의 파장은 수행사가 사용 경험이 있는 808nm로 결정하였으며, 균등한 밝기 분포를 가진 레이저 중 라인이 얇은 ZQ-LASER를 본 연구에 사용하기로 결정하였다. 표 3.14는 주요 포인트 레이저 장치의 사양을 비교한 것이며, ZQ-LASER의 세부사양은 표 3.15와 같다.

표 3.14 포인트 레이저 사양 비교

구분	KM 1000	LUMI-LASER300	SKIN-L1000
빔 파장	850nm	860nm	850nm
레이저 출력	1.1w 이상		
기타	포인트 방식	면방식	면방식
사진			

표 3.15 포인트 레이저(ZQ-LASER) 세부 사양

Output power	up to 6,000mW
Wavelength	808nm
Power stability	±1% over operating temperature range within 24h, ±5% over complete lifetime±1% over operating temperature range within 24h, ±5% over complete lifetime
Wavelength vs. temperature	Typ. ±1nm over operating temperature range
Pointing stability	< 15μrad / °C
Projection	line homogeneous, line flat top, dot circular, dot elliptical
Line homogeneous profile	10°, 20°, 30°, 45°, 60°, 75°, 90°
Point	Elliptical
Adjustable focus	yes
Focus range	50mm to 10,000mm
Divergence of beam FWHM	0.3mrad (1 / e²), 0.2mrad (FWHM)
Intensity control	yes

다. 주변광 차단필터 선정

채귀반사 휘도 측정기는 조사한 광량대비 반사되어 돌아오는 양을 측정해야 하므로 인위적인 광원에서 발산한 광원 이외의 주변광은 반드시 제거되어야 한다. 그림 3.49는 주변광 차단 필터 역할을 도기한 것이다.

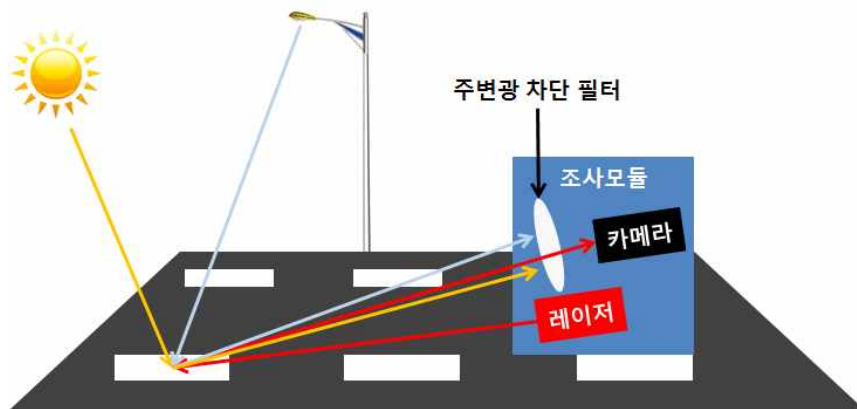
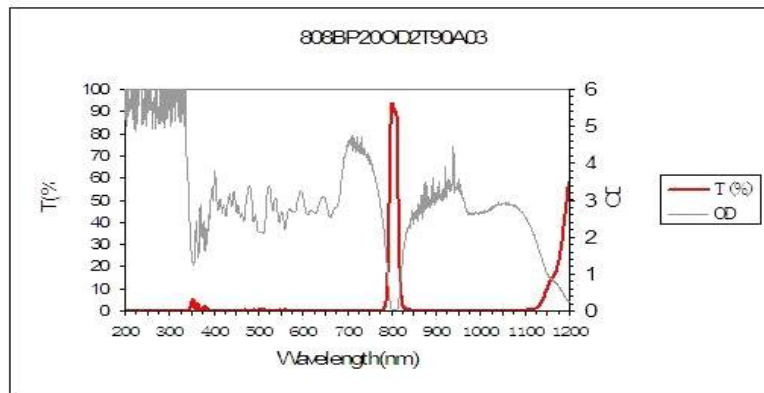


그림 3.49 차선도색 채귀반사 휘도 측정기의 주변광 차단필터 역할

본 연구에서는 단일 파장인 808nm의 레이저 광원을 사용하고 있다. 따라서 808nm의 파장대만 통과시키는 밴드패스 필터를 구성함으로써 주변광을 제거할 수 있다. 태양광 속에도 808nm 파장대의 적외선이 존재하지만 이 파장대의 빛의 세기만을 비교해 보면 라인레이저에 비해 무시할 만한 수준이다. 적용 레이저 파장 특성 및 영상센서의 적용성을 고려하여 해당 필터의 제작 사양을 그림 3.50과 같이 결정하였다.

- 필터 크기 : $\phi 25 * 0.55\text{mm}$
- 패스 파장 영역 : $808 \pm 20\text{nm}$

- 패스 영역 투과율 : 90%이상



Specifications:

Substrate material: Float glass
 Dimension(mm): 11.4x11.4, Ø12.5x6(mounted), Ø25.4x6(mounted), Custom
 Angle of incidence: 0°
 Center wavelength: 808 nm
 FWHM: 20 nm
 Tpeak: T > 90% at 808 nm
 Blocking: OD2-A [What is OD?](#)
 Min. clear aperture(mm): >11x11(11.4x11.4); >Ø8.7(v12.7); >Ø21(Ø25.4)
 Other: Customed, Store id: B05-3-5

Note: Other dimension and specification are available upon request.

그림 3.50 제작된 밴드패스 필터 사양

라. 재귀반사광원 수광센서 선정

광원 수광센서는 본 연구에서 중요한 요소 중 하나이다. 본 연구에서는 재귀반사회도의 측정 범위를 $10 \sim 1000 \text{ mcd/m}^2/\text{lux}$ 로 설정하였다. 측정 분해능을 1로 가정하면 최소 Video Data Output(VDO)이 10bit인 카메라가 필요하다. 만약 카메라 주변요소(조리개, 셔터 등)를 미세조정하여 입사되는 광량을 사용자가 필요로 하는 범위에 정확히 조절 할 수 있다면 VDO 10bit 카메라로도 본 과업을 수행할 수 있다. 그러나 보통 조리개는 정해진 몇 단계로만 조절이 가능하므로 여유폭을 고려하여 최소한 VDO 12bit를 가지는 카메라가 필요하다. 또한 80km의 조사 속도에서 1m마다 데이터를 획득하기 위해서는 초당 30프레임 이상의 속도를 가지는 카메라가 필요하다. 위 사양을 만족하는 광원 수광센서용 카메라로 3개의 제품을 표 3.16과 같이 선정하였다.

표 3.16 재귀반사 수광용 카메라 종류

수광카메라 종류	A	B	C
Video Data Output Level	12Bit BW	12Bit BW	14Bit BW
사진			

마. 테스트 지그 제작

선정된 카메라와 레이저로 성능 테스트를 하기 위해 카메라와 레이저를 ASTM E1710 규정에 맞도록 고정시켜 주는 지그를 그림 3.51과 같이 제작하였다.

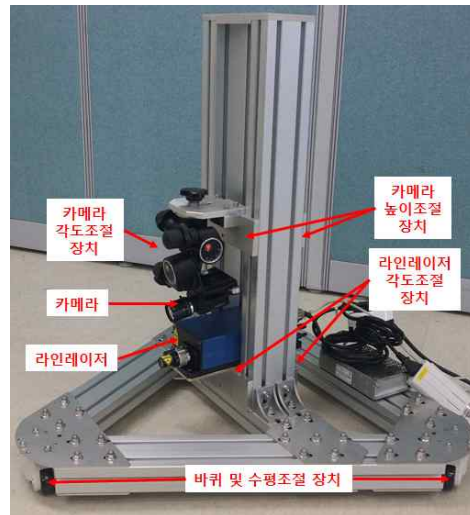


그림 3.51 휘도측정 테스트 지그

바. 야간 테스트

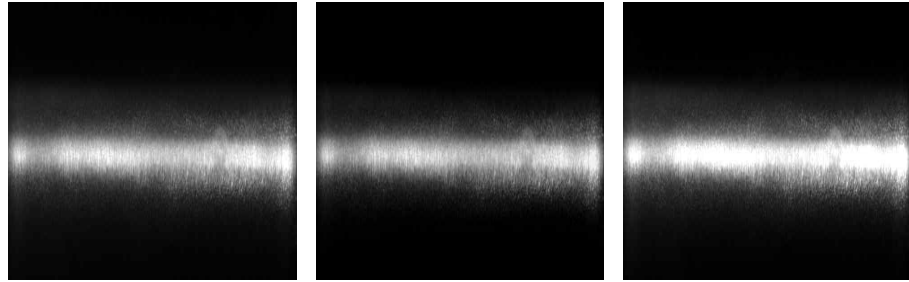
3개 종류의 재귀반사 수광용 카메라와 레이저를 ASTM E1710 규정에 맞도록 각도를 설정하면 전방 약 8m 지점에 레이저 라인이 형성된다. 75mm렌즈를 사용하여 촬영하면 약 1.3m의 스캔폭이 확보된다. 센서가 위아래로 기울어 ASTM E1710 규정에 맞지 않을 때의 데이터는 불필요하므로 카메라 촬영 영역 중 Y축은 감소시킬 수 있다. 이러한 방식으로 1회 데이터 전송량을 감소시켜 초당 획득할 수 있는 프레임을 증가시킬 수 있다. 이러한 기능은 3개의 카메라 모두 지원하였으며 더불어 재귀반사 수광 감도를 비교하는 야간 테스트를 그림 3.52와 같이 수행하였다. 수행방법은 카메라 모두 동일한 설정(셔터스피드, 렌즈 및 게인값) 후 진행하였다. 감도테스트 결과 그림 3.53 및 표 3.17과 같이 “C”카메라의 성능이 가장 우수한 것으로 나타났으며, 본 과업의 재귀반사 수광용 카메라로 선정하였다.



그림 3.52 재귀반사 수광용 카메라 실외 테스트



(a) 레이저 출력 (20%), 좌측부터 카메라 A, B, C



(b) 레이저 출력 (50%), 좌측부터 카메라 A, B, C

그림 3.53 각 카메라 별 재귀반사 수광 영상

표 3.17 재귀반사 수광용 카메라 감도 테스트 결과

레이저 출력[상태파워]		10%	20%	50%
재귀반사 수광용 카메라 종류별 감도	A	65	95	192
	B	37	73	172
	C	72	108	210

사. 필터 실외테스트

외부광원 중 가장 밝은 태양광이 가장 강한 시간대에 그림 3.54와 같이 테스트를 위한 환경을 구축하였다. 실외테스트 목적은 선정된 재귀반사 수광용 카메라에서 다양한 외부광원 차단용 광학필터의 성능을 확인하기 위함이다.



그림 3.54 광학필터의 외부광원 차단효과 시험

테스트 결과 필터 미장착 상태에서 보였던 주변광(태양광)에 의한 이미지가 필터 장착 후 제거됨을 그림 3.55와 같이 확인하였다.

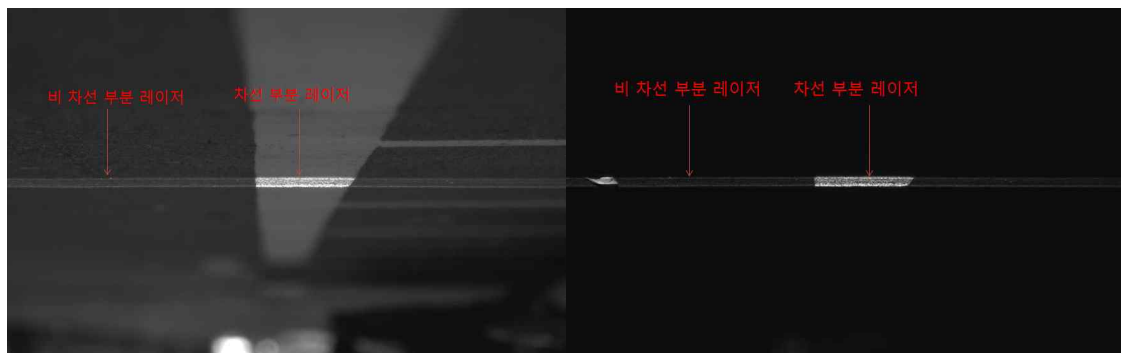
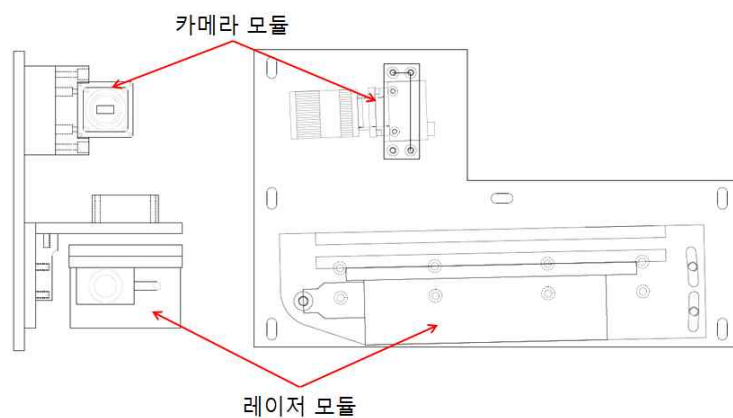


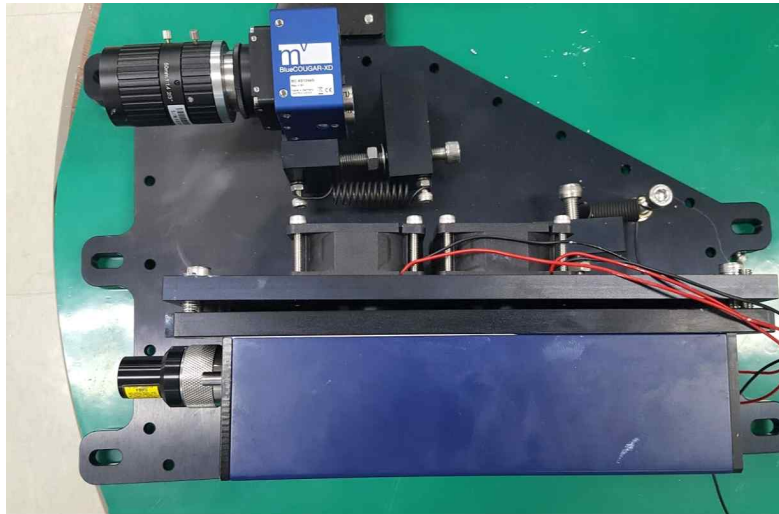
그림 3.55 광학필터의 외부광원 차단효과 시험

아. 프레임 제작

차량에 장착하여 테스트할 수 있는 재귀반사 휘도측정기 기구를 재귀반사 휘도 측정 기준인 ASTM 규격에 적합하도록 그림 3.56과 같이 구성하였다.



(a) 휘도 측정기 설계



(b) 제작된 시작품

그림 3.56 재귀반사 휘도 측정기 설계 및 시작품 제작

기구 구성 시행착오를 반복하여 차량에 거치할 수 있도록 수정/보완하였으며 차량에 장착하여 조사할 수 있도록 조사장비구성을 그림 3.57과 같이 완료하였다.



그림 3.57 재귀반사 휘도 측정기 차량

자. 재귀반사 휘도 측정 알고리즘

제작된 모듈로 실제 차선을 촬영한 후 차선 부분의 재귀 반사된 데이터를 추출하는 일련의 과정은 그림 3.58과 같다.



그림 3.58 재귀반사 휘도 추출 과정

주변광 차단 필터를 통과하여 카메라로 촬영된 영상에서 스레시 홀딩기법 및 이진화 처리를 통해 차선영역을 추출하고, 차선 영역의 밝기 평균값을 산출한다. 이렇게 계산된 밝기값은 캘리브레이션 팩터값을 적용하여 실제 휘도값으로 계산된다. 촬영된 영상을 후처리를 통해 휘도값을 산출하여, 조사 결과를 바로 확인할 수 있도록 실시간 처리 알고리즘을 적용하였다.

조사 영상에서 실시간으로 차선 위치를 찾아 밝기를 추출하고 캘리브레이션 팩터를 적용하여 휘도값을 계산하기 위해서 GPU(Graphic Processing Unit)를 적용하였다. GPU는 그래픽 카드에 있는 연산유닛으로 단순한 연산을 병렬로 처리할 수 있다. 조사된 영상을 GPU를 이용하여 병렬처리하면 30프레임 이상의 영상도 실시간 처리가 가능하다. GPU를 지원하는 GeForce 계열 그래픽 카드를 선정하고, 그래픽 카드 제조사에서 제공하는 CUDA SDK를 사용하여 실시간 휘도 산출을하기로 결정하고, SDK 설치 및 병렬처리 로직을 그림 3.59와 같이 결정하였다.

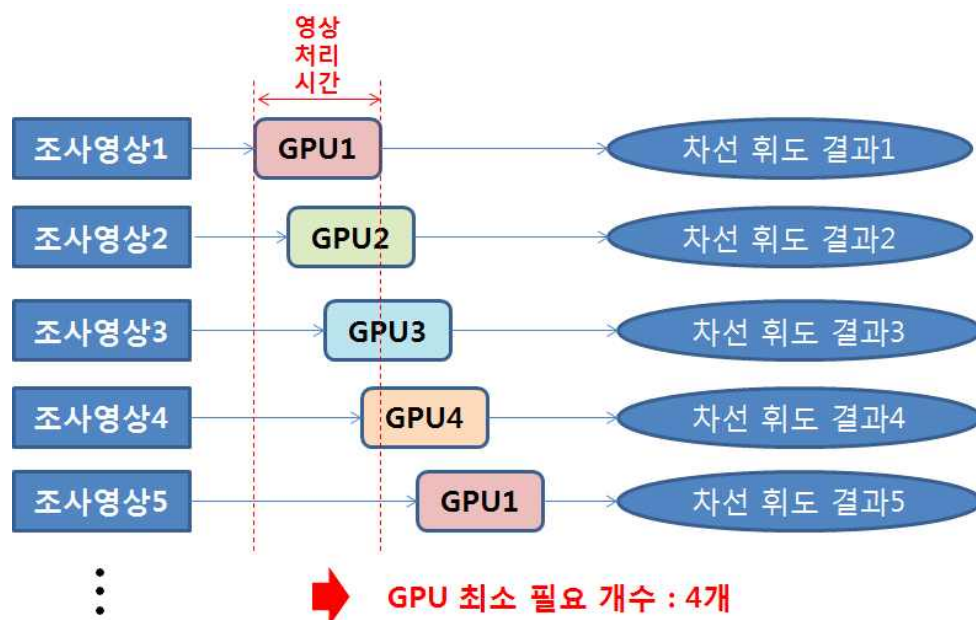


그림 3.59 GPU 연산 유닛을 활용한 병렬 처리 로직

차선 추출 알고리즘 성능 테스트를 위해 공용중인 도로에서 테스트를 수행하였다. 약 1km구간에 대해 주간 테스트결과 90%이상의 차선영역을 검출하였다. 그림 3.60은 재귀반사 밝기에 의해 정상적으로 추출된 차선 예를 나타낸 것이다.

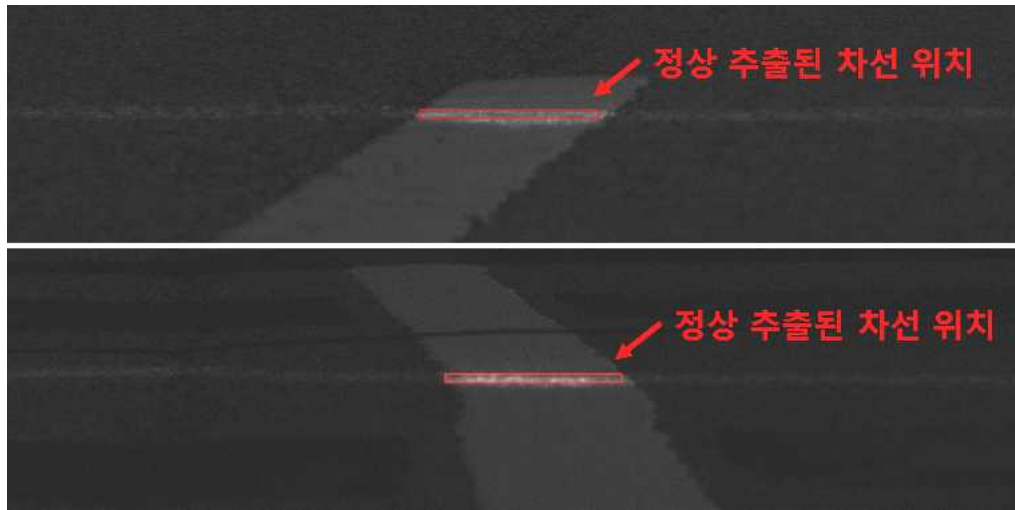


그림 3.60 재귀반사 밝기에 의한 차선 추출 예

차. 조사프로그램 개발

휘도 조사프로그램은 기 개발된 차선 상태 조사프로그램과 통합하여 개발하였다. 이는 휘도 조사모듈과 상태 조사 모듈을 동시 또는 단독으로 사용할 수 있게 하기 위함이다. 개발된 조사 프로그램에서는 설정을 통해 두 모듈을 동시 또는 단독으로 조사할 수 있다. 수요처 실무자의 의견으로 조사 시 운전 가이드라인이 필요하다는 의견과 조사 프로그램 창 배치 초기화 기능이 필요하다는 의견을 반영하여 그림 3.61과 같이 조사 프로그램을 수정하였다.



그림 3.61 차선 휘도 및 상태 통합조사 프로그램

그림 3.62와 같이 캘리브레이션을 수행하기 위해서는 차량과 타겟의 위치를 정확하게 만들어 주어야 한다. 측정각(관찰각)은 차량에 타고 있는 사람이 30m 전방을 바라보는 방향과 헤드라이트가 30m 전방을 비추는 방향 사이각을 의미하며, ASTM E1710에 이 각을 1.05도로 명시하고 있다. EN1436에는 같은 각을 다르게 표현하고 있는데, 차량에 타고 있는 사람이 30m 전방을 바라볼 때 이 방향이 노면과 이루는 각으로 2.29도로 명시하고 있다. 이를 만족하는 8.8m 위치에 캘리브레이션 타겟을 정확히 놓고 캘리브레이션을 진행하여야 한다.

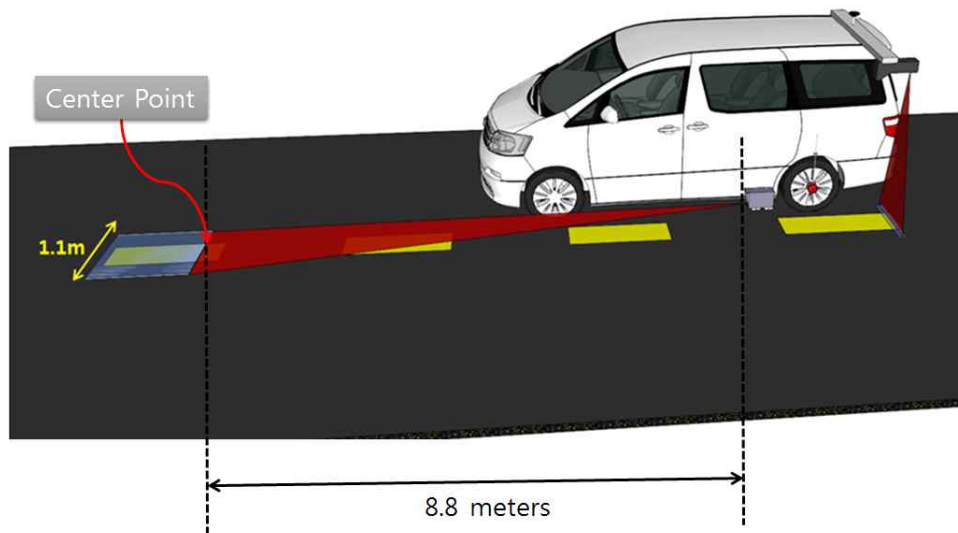


그림 3.62 표준 캘리브레이션 위치

그림 3.63은 캘리브레이션 메뉴를 나타낸다. 캘리브레이션을 수행하기 위해서는 반드시 평평한 노면에서 수행하여야 한다. 캘리브레이션은 황색 차선, 흰색 차선별로 수행하며, 각각의 타겟을 이용하여 기준 값과 최대값, 최소값을 입력 후 캘리브레이션 버튼을 클릭하여 캘리브레이션을 수행한다. 캘리브레이션 결과값은 캘리브레이션 팩터값이 되며 이 값을 이용하여 검출된 차선의 휘도값을 도출한다. 또한 2중 점선, 실선과 같이 2개의 차선이 존재하는 구간에 대해서도 측정이 가능하도록 캘리브레이션 프로그램을 구성하였다.

황색 캘리브레이션				
날짜	2016/08/22			
기준 값	320.00	결과 값	0.8956	
최대 값	1500.00	최소 값	150.00	
캘리브레이션				

흰색 캘리브레이션				
날짜	2016/08/22			
기준 값	400.0000	결과 값	0.7254	
최대 값	1500.00	최소 값	150.00	
캘리브레이션				

그림 3.63 캘리브레이션 프로그램

카. 성능 테스트

① 측정 속도 테스트

- 조사간격 : 0.5m
- 조사속도 : 80km/h(가상조사)
- 조사거리 : 1km 내외

DMI의 가상조사 기능을 이용하여 시속 80km/h의 조사 속도를 설정한 후 데이터를 취득하여 데이터 누락 여부를 확인하였으며 표 3.18과 같이 10회의 조사에서 모두 누락없이 데이터를 취득하였다.

표 3.18 차량 탑재형 휘도 측정기 조사 속도 테스트 결과

테스트 횟수	조사 거리[km]	조사속도 [km/h]	측정속도 [회/초]	데이터 누락 개수
1	1.112	80km/h	44	0
2	0.980	80km/h	44	0
3	1.032	80km/h	44	0
4	1.219	80km/h	44	0
5	9.985	80km/h	44	0
6	1.160	80km/h	44	0
7	1.206	80km/h	44	0
8	1.152	80km/h	44	0
9	1.232	80km/h	44	0
10	0.998	80km/h	44	0

② 휘도 정확도 테스트

- 조사간격 :
 - a. 기준장비(휴대용 휘도 측정기) : 1m 간격을 측정하여 평균값 사용
 - b. 개발 장비 : 0.5m 간격을 측정하여 평균값 사용
- 조사속도 : 0~40km/h
- 조사거리 : 50m ~ 300m

신설 차선(백색) 및 노후 차선(황색)을 테스트 사이트로 선정하고, 휴대용 휘도 측정기를 이용하여 기준값을 측정한 후, 장비의 조사 결과와 비교하였다. 그림 3.64는 휘도 측정 정확도 시험을 수행하는 진경이다. 시험 결과, 표 3.19와 같이 신설 및 노후 차선 모두 휴대용 측정기 대비 10% 미만의 오차를 보였다.



그림 3.64 휘도측정 정확도 검증

표 3.19 측정 정확도 테스트 결과

구분	측정1 [mcd/m ² /lux]	측정2 [mcd/m ² /lux]	측정3 [mcd/m ² /lux]	기준값 [mcd/m ² /lux]	최대 오차 [%]	목표오차 [%]
신설차선	428	425	428	421	1.7	≤10.0
노후차선	55	51	54	51	8.7	≤10.0

③ 측정 조건(주/야간)에 따른 측정값 편차

- 조사간격 :

a. 기준장비(휴대용 휘도 측정기) : 1m 간격을 측정하여 평균값 사용

b. 개발 장비 : 0.5m 간격을 측정하여 평균값 사용

- 조사속도 : 0~40km/h

- 조사거리 : 300m

외부 광원이 큰 차이를 보이는 주간과 야간의 환경 특성 상, 측정값에 미세한 영향을 줄 수 있기 때문에 그림 3.65와 같이 동일한 차선위치에서 주간 및 야간 주행 시험을 통해 휘도값을 비교하였다. 그 결과 표 3.20과 같이 주야간 모두 10% 미만의 오차를 나타냈다.



그림 3.65 주야간 테스트

표 3.20 주야간 측정 데이터 편차

구분	주간 [mcd/m ² /lux]	야간 [mcd/m ² /lux]	기준값 [mcd/m ² /lux]	주간오차 [%]	야간오차 [%]	목표오차 [%]
1회	428	441	421	1.6	4.8	≤10.0
2회	425	438	421	1.1	4.2	
3회	428	441	421	1.7	4.9	

④ 스캔 폭

개발된 휘도 측정기의 스캔폭을 확인하기 위해 그림 3.66과 같이 높이가 있는 물체를 1.1m 간격으로 조사 위치에 배치하고, 실제 조사 화면에서 물체를 확인하였다.

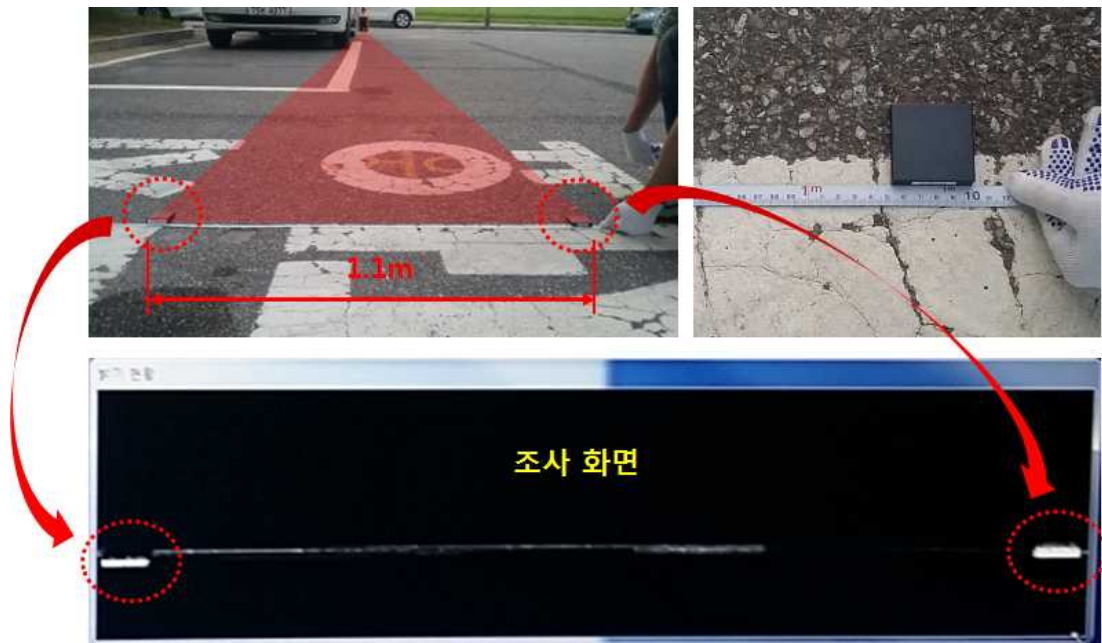


그림 3.66 휘도 측정기 스캔 폭

1차 현장테스트 결과 본 연구에서 설정한 세부 목표성능을 모두 구현한 것으로 확인하였다.

타. 고속도로 차선도색 현장 평가

① 평가 개요

상기에서 기술된 제작장비의 휘도 측정 성능을 종합적으로 평가하고자, 본 연구의 1차 수요기관인 한국도로공사에서 관리하는 고속도로 차선을 대상으로 현장 평가를 실시하였다. 현장 평가구간의 개요도는 그림 3.67과 같다.

- 위치 : 한국도로공사 시험도로(중부내륙선)
- 평가 구간 개요

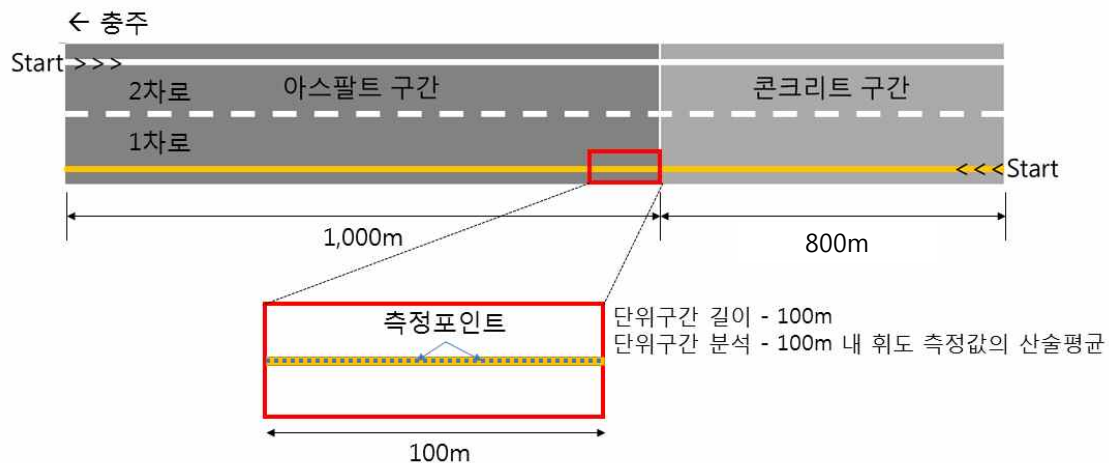


그림 3.67 고속도로 차선 평가구간 개요

- 측정 순서 : 휴대용 휘도측정기(주간) → 개발장비(주간) → 개발장비(야간)
- 측정 방법
 - 휴대용 휘도측정기 : 4m 간격 휘도 측정
 - 차량형 개발장비 : 40, 60, 80km/h 주행 중 측정
- 평가 방법 : 휴대용 휘도측정기 대비 100m 단위구간 평균휘도값 오차 비교
(한국도로공사 현행 평가방법 적용)

현장 평가를 통해 본 연구에서 확인하고자 하는 사항은 다음과 같다.

- 포장 형식별 휘도 측정 성능 평가
- 주행속도(조사속도)별 휘도 측정 성능 평가
- 차선 색상별 휘도 측정 성능 평가
- 공용 중인 고속도로 차선의 휘도 현황 파악

다음 그림 3.68은 시험도로에서 재귀반사 휘도를 측정하는 장면을 나타낸 것이다.



(a) 휴대용 재귀반사 휘도 측정 장면



(b) 차량형 개발장비의 휘도 데이터 분석 모습



(c) 개발장비의 주간 휘도 측정 장면



(d) 개발장비의 야간 휘도 측정 장면

그림 3.68 현장 평가 모습

② 평가 결과

o 휴대용 측정기 휘도 데이터 분석

현재 휴대용 장비를 이용한 차선 휘도의 현장 평가방법과 절차에 대해 명문화되어 있지 않으며, 한국도로공사에서는 자체적으로 100m의 단위 구간에 대해 5개 미만의 임의의 지점 측정값을 산술평균하여 단위 구간의 대푯값으로 평가하고 있다. 이에 본 연구에서는 평가 단위구간은 100m를 그대로 사용하되, 4m 간격으로 휘도를 측정하여 25개의 샘플을 바탕으로 단위구간의 휘도값을 분석하였다.

그림 3.69는 아스팔트 백색 차선의 초기 100m 단위구간 내 휘도 데이터의 분포를 나타낸 것이다. 167 ~ 247mcd/m²/lux 범위의 분포를 보였으며 동일 평가구간 내에서 데이터의 편차가 크게 분포하고 있는 것으로 나타났다. 이는 차선의 실제 휘도가 측정 위치에 민감하게 달라질 수 있다는 점을 의미하므로 이에 각 구간 샘플들의 분포를 변동계수를 통해 정량적으로 검토하여 그림 3.70에 나타내었다.

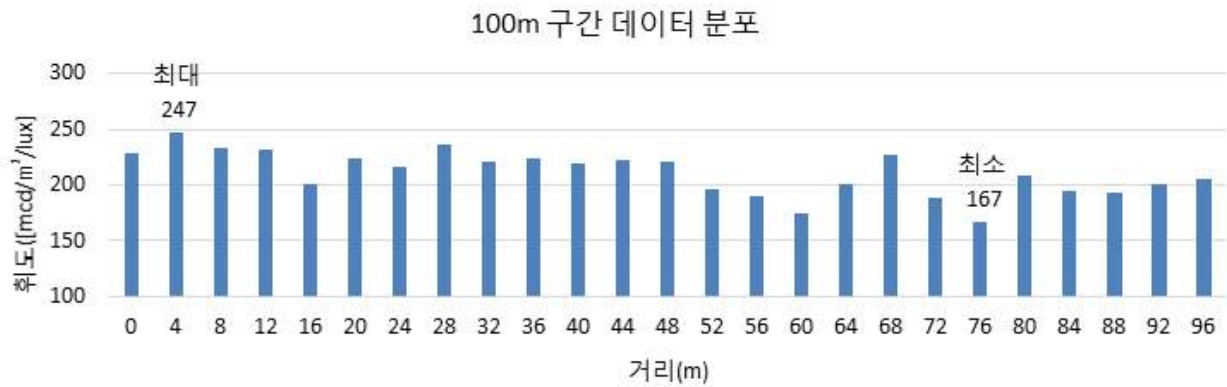


그림 3.69 100m 구간 내 샘플의 수치 분포



그림 3.70 각 단위구간 별 변동계수 분석 결과

변동계수(Coefficient of variation)는 표준편차와 평균값의 비율로 정의되며 변동계수가 클수록 평균값 대비 표준편차의 크기가 크다는 것을 의미한다. 이는 각 샘플들의 편차가 어느 정도 수준인지 가늠할 수 있는 기초 통계분석 방법이다. 그림 3.70에서 보는 바와 같이 황색 차선의 경우 최대 28%, 백색 차선의 경우 최대 22%의 변동계수값을 나타내었다. 전반적으로 황색 차선의 변동계수가 10% 이상으로 백색 차선에 비해 상대적으로 높게 분포하고 있음을 보여준다.

이러한 점은 100m 단위길이 내에 휘도의 편차가 크게 나타나고 있음을 의미하며, 일반적으로 평균값이 유의미한 대표성을 갖기 위해서는 샘플 수가 많을수록 유리하다. 따라서 기존의 5개 미만의 샘플을 바탕으로 단위 구간의 휘도값을 결정하는 방식보다 통계적으로 더 정확한 평균값을 측정한 것으로 판단할 수 있다.

○ 개발장비 휘도 데이터 분석

표 3.21은 개발장비로 측정한 평균휘도값과 휴대용 측정장비로 측정된 휘도 기준값과의 오차를 정리한 것이다. 본 연구에서 설정한 오차 목표는 10% 미만이며, 각 평가 단위구간 모두 목표를 만족한 것으로 분석되었다.

표 3.21 휘도측정 정확도 테스트 결과

차 선 색 상	포 장 형 식	거 리 [m]	재귀반사 휘도[mcd/m ² /lux]							최대 오차 [%]	목 표 오차 [%]
			주간 40km/h	주간 60km/h	주간 80km/h	야간 40km/h	야간 60km/h	야간 80km/h	기준값		
백 색	아 스 팔 트 AC	100	214	211	221	214	215	213	212	4.2	≤10.0
		200	218	211	222	219	222	217	208	6.7	
		300	179	175	174	169	173	174	178	5.1	
		400	186	183	181	179	184	185	184	2.7	
		500	189	184	189	187	194	188	181	7.2	
		600	195	193	183	192	188	183	195	6.2	
		700	212	193	190	185	189	196	204	9.3	
		800	197	194	184	180	188	179	193	7.3	
		900	200	204	198	189	189	187	192	6.3	
		1000	197	189	179	180	178	183	182	8.2	
	콘 크 리 트 CC	1100	169	177	173	177	165	172	171	3.5	
		1200	180	174	169	172	161	176	168	7.1	
		1300	184	177	160	156	155	160	170	8.8	
		1400	197	195	187	179	181	184	188	4.8	
		1500	190	189	183	181	175	197	192	8.9	
		1600	193	185	179	170	172	178	181	6.6	
		1700	422	423	368	365	371	420	390	8.5	
		1800	413	426	394	399	383	401	412	7.0	
황 색	콘 크 리 트 CC	100	115	113	109	114	117	118	115	5.2	≤10.0
		200	119	120	116	123	123	121	119	3.4	
		300	132	128	138	125	129	131	137	8.8	
		400	130	130	127	125	128	124	123	5.7	
		500	113	108	108	102	102	102	107	5.6	
		600	148	146	138	144	154	149	145	6.2	
		700	126	119	117	116	115	115	119	5.9	
		800	119	117	112	113	111	114	110	8.2	
	아 스 팔 트 AC	900	108	105	103	99	104	103	99	9.1	
		1000	115	113	111	113	111	110	121	9.1	
		1100	109	112	108	106	106	107	109	2.8	
		1200	118	117	120	109	113	115	118	7.6	
		1300	128	130	130	129	133	135	133	3.8	
		1400	123	130	127	125	127	128	122	6.6	
		1500	119	124	123	119	126	127	127	6.3	
		1600	115	116	118	115	113	125	118	5.9	
		1700	115	112	113	109	110	108	118	8.5	
		1800	124	121	115	114	122	122	119	4.2	

전술된 바와 같이 각 데이터는 평가구간의 샘플들로부터 얻어진 평균값이다. 따라서, 평균값과 평균값의 통계적 유의성을 검정하기 위해 통계분석 프로그램인 SPSS를 이용하여 그림 3.71과 같이 분산분석(ANOVA, ANalysis Of VAriance)을 수행하였다. 이 통계기법은 3개 이상의 집단평균을 비교하기 위해 비교과정에 분산을 사용하는 방법이며 각 집단의 평균이 동일하다는 가설을 귀무가설로 설정한다. 본 연구에서는 SPSS 통계분석 프로그램을 활용하여 일원배치 분산분석(1-way ANOVA)을 수행하였으며, 추가적으로 각 집단 간의 유의확률을 검토하였다. 신뢰수준을 의미하는 유의수준은 95%신뢰도에 해당하는 0.05를 설정하여 유의확률과의 비교를 통해 귀무가설의 통계적 타당성 즉, 개발장비의 평균값과 휴대용 측정기의 평균값이 통계적으로 일치한다고 평가할 수 있는지를 검토하였다.

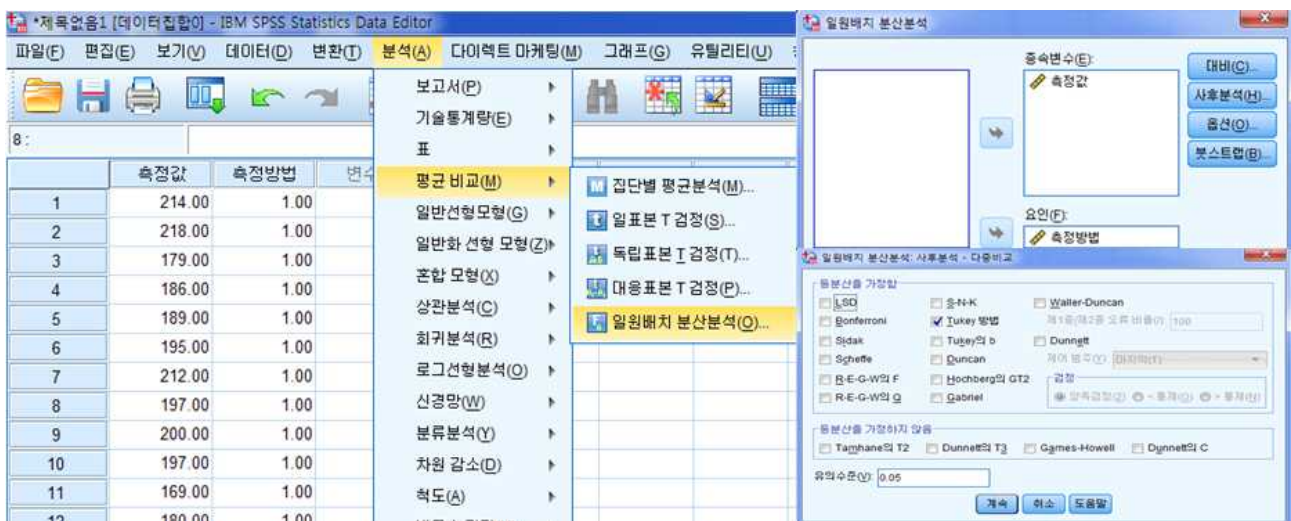


그림 3.71 SPSS를 활용한 통계분석

그림 3.72는 백색 및 황색 차선의 평가값들을 바탕으로 다음의 귀무가설을 검정한 결과이다.

귀무가설 : 주간 40km/h = 주간 60km/h = 주간 80km/h =
야간 40km/h = 야간 60km/h = 야간 80km/h =
기준값(휴대용 측정장비)

일원배치 분산분석

측정값	제공합	df	평균 제공	F	유의확률
집단-간	2978.714	6	496.452	.101	.996
집단-내	585107.000	119	4916.866		
합계	588085.714	125			

(a) 백색 차선

일원배치 분산분석

측정값	제공합	df	평균 제공	F	유의확률
집단-간	196.778	6	32.796	.280	.945
집단-내	13937.000	119	117.118		
합계	14133.778	125			

(b) 황색 차선

그림 3.72 ANOVA 검정 결과

백색과 황색 차선의 유의확률은 각각 0.996, 0.945로 나타나 각 시험결과가 통계적으로 차이가 없는 것으로 나타났다. 또한 Tukey방법에 의한 사후검정을 실시한 결과, 집단 간 평균차이도 통계적으로 차이가 없는 것으로 나타났다.

표 3.22는 주/야간 시험결과의 평균값 집단을 추가하여 총 9개의 집단 간 유의확률을 검토한 결과이다. 모든 경우에서 유의수준 0.05를 상회하여 각 집단 간 통계적 유의성이 있는 것으로 검토되었다. 즉, 차량의 주행속도와 주/야간 여부는 포장형식과 차선 색상에 상관없이 휘도 측정 결과에 영향을 주지 않는 것으로 판단할 수 있다.

표 3.22 각 측정 집단 간 유의확률 검토 결과

구분	백색, 아스팔트								
	set1	set2	set3	set4	set5	set6	set7	set8	set9
set1	1	0.376	0.335	0.499	0.162	0.3	0.189	0.204	0.306
set2	-	1	0.809	0.861	0.499	0.785	0.592	0.612	0.883
set3	-	-	1	0.706	0.715	0.989	0.821	0.835	0.904
set4	-	-	-	1	0.425	0.678	0.502	0.521	0.753
set5	-	-	-	-	1	0.712	0.871	0.862	0.581
set6	-	-	-	-	-	1	0.823	0.837	0.885
set7	-	-	-	-	-	-	1	0.988	0.687
set8	-	-	-	-	-	-	-	1	0.706
set9	-	-	-	-	-	-	-	-	1
구분	백색, 콘크리트								
	set1	set2	set3	set4	set5	set6	set7	set8	set9
set1	1	0.993	0.744	0.913	0.721	0.658	0.889	0.753	0.832
set2	-	1	0.753	0.918	0.73	0.667	0.895	0.761	0.839
set3	-	-	1	0.833	0.968	0.895	0.862	0.91	0.916
set4	-	-	-	1	0.801	0.734	0.971	0.833	0.914
set5	-	-	-	-	1	0.924	0.837	0.972	0.889
set6	-	-	-	-	-	1	0.77	0.901	0.820
set7	-	-	-	-	-	-	1	0.861	0.941
set8	-	-	-	-	-	-	-	1	0.921
set9	-	-	-	-	-	-	-	-	1
구분	황색, 아스팔트								
	set1	set2	set3	set4	set5	set6	set7	set8	set9
set1	1	0.857	0.562	0.304	0.612	0.449	0.469	0.51	0.475
set2	-	1	0.751	0.844	0.286	0.715	0.91	0.624	0.92
set3	-	-	1	0.89	0.45	0.942	0.786	0.846	0.692
set4	-	-	-	1	0.354	0.84	0.868	0.74	0.774
set5	-	-	-	-	1	0.527	0.356	0.603	0.272
set6	-	-	-	-	-	1	0.749	0.91	0.661
set7	-	-	-	-	-	-	1	0.668	0.93
set8	-	-	-	-	-	-	-	1	0.578
set9	-	-	-	-	-	-	-	-	1
구분	황색, 콘크리트								
	set1	set2	set3	set4	set5	set6	set7	set8	set9
set1	1	0.66	0.448	0.687	0.414	0.681	0.591	0.552	0.504
set2	-	1	0.745	0.967	0.7	0.972	0.894	0.849	0.82
set3	-	-	1	0.712	0.952	0.806	0.866	0.91	0.919
set4	-	-	-	1	0.668	0.943	0.863	0.818	0.786
set5	-	-	-	-	1	0.767	0.822	0.866	0.871
set6	-	-	-	-	-	1	0.934	0.894	0.873
set7	-	-	-	-	-	-	1	0.958	0.939
set8	-	-	-	-	-	-	-	1	0.985
set9	-	-	-	-	-	-	-	-	1
set No.	set1	set2	set3	set4	set5	set6	set7	set8	set9
집단 구분	주간 40km/h	주간 60km/h	주간 80km/h	주간 평균	야간 40km/h	야간 60km/h	야간 80km/h	야간 평균	기준값

3. 차선품질 유지관리 프로그램 개발

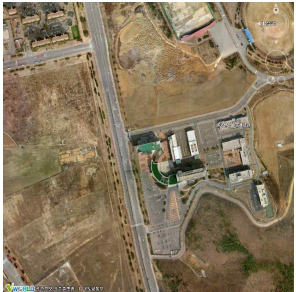
방대한 도로망에 설치된 차선헌태를 용이하게 관리하고자 취득 데이터를 일목요연하게 표출 및 조회할 수 있는 관리프로그램을 제작하였다. 차선헌색 관리프로그램에서 개발해야할 핵심적인 항목 및 기능은 다음과 같다.

- 국내 웹 GIS맵을 이용한 조사 위치 및 상태 표시 디스플레이 모듈 개발
- 이력관리 기능
- 보수물량 산출을 위한 자료 수집 및 반영
- 보고서 생성 모듈 개발
- 주변 현황 영상 연동 모듈 개발
- 불량구간/정상구간 표시기능
- Stand-alone 시스템으로 프로그램 구현

가. 웹 GIS맵을 이용한 조사위치 및 상태 표시

국내 서비스중인 웹 GIS 맵은 다수 존재한다. 제공되는 서비스 기능을 요약하면 표 3.23과 같다. 이 중 국토교통부에서 제공하는 V world 서비스는 안정화 단계라 선정에서 제외하였으며, 구글 지도는 위성지도의 해상도가 다른 지도에 비해 낮아 제외하였다. 이외 포털사이트에서 제공되는 지도서비스는 비슷한 성능을 보였으며, 스트리트 뷰의 해상도가 더 높은 D사의 지도를 본 과제에 적용하는 것으로 결정하였다.

표 3.23 웹 GIS맵 비교

구분	G*****	V*****	D***
정보갱신빈도	낮음	높음	높음
인터페이스	편리	보통	편리
기타	국내정보에 취약	모듈이 무거움	일부 정보제한 有
사진			

선정된 지도 서비스에서 제공되는 API(Application Program Interface)를 활용하여 웹 GIS상에 선형정보를 표시 할 수 있음을 확인하였다. 이러한 표시 방법은 그림 3.73과 같이 주행궤적뿐 아니라 차선헌태표시에도 활용할 수 있다.

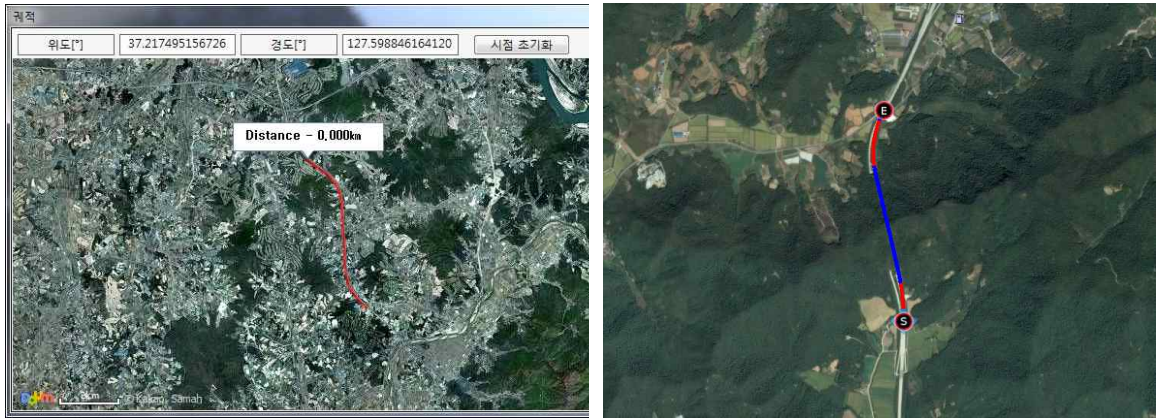


그림 3.73 API를 이용한 궤적정보 표시 및 색상정보 표출 예

나. 이력관리 기능

이력관리는 크게 두가지 항목이 포함된다. 첫 번째는 차선의 상태인 탈리 상태 및 차선 두께이며, 두 번째로는 재귀반사 휘도이다. 차선품질 유지관리 프로그램은 다중 프로젝트 로딩 기능을 이용하여 이력관리 기능을 구현하였다. 다중 프로젝트 로딩 기능은 측정된 여러 데이터를 한 프로그램에서 로딩하여 비교해 볼 수 있는 기능이다. 그림 3.74는 이력관리의 프로토타입을 나타낸 것이다. 좌측에 로딩된 연차별 혹은 차로별 조사 자료명이 표출되고 우측에는 차트와 표로 데이터의 변화 추이를 확인할 수 있도록 구성하였다. 동 구간에 대한 이력 조사 데이터는 동일한 폴더상에 위치하도록 하였으며, 이 상위 폴더를 이력관리 모듈에서 로딩할 수 있도록 구성하였다.

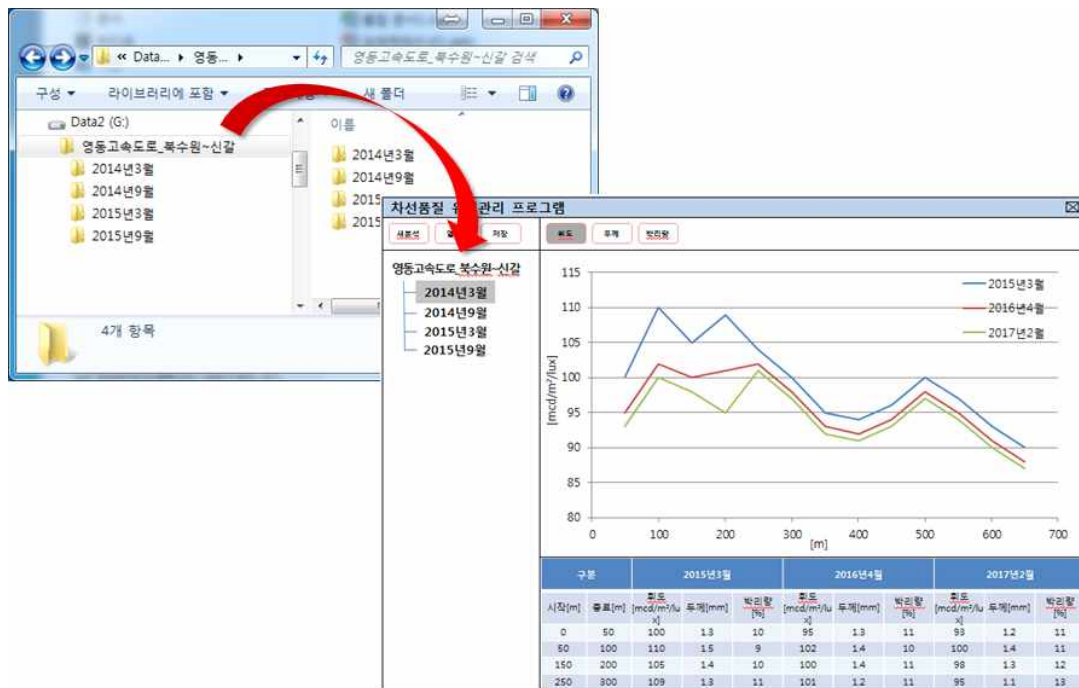


그림 3.74 이력관리를 위한 다중프로젝트 로딩기능 적용 예

다. 보수물량 산출

보수 대상 구간은 재귀반사 휘도 불량구간을 기반으로 결정되며, 보수물량 산출시 필요한 기준 단가는 매년 변동이 있을 수 있다. 따라서 기준 단가는 변동이 있을 때 마다 새로이 적용할 수 있도록 기준 단가파일 생성 기능이 필요하다. 단, 차선의 두께와 박리량에 대한 보수 기준은 아직 마련되지 않은 관계로 보수 물량의 입력 데이터는 휘도 데이터로 한정되었다. 개발된 보수물량 산출 알고리즘과 샘플 데이터에 대한 적용 결과는 그림 3.75와 같다. 또한 상태별 우선순위 정렬 기능을 추가 구현하여 상태가 좋지 않은 구간부터 우선적으로 유지 보수가 가능하도록 하였다. 뿐만 아니라 확보된 예산범위 내에서 우선순위 별 보수 구간을 찾아주는 기능을 함께 포함하였다.

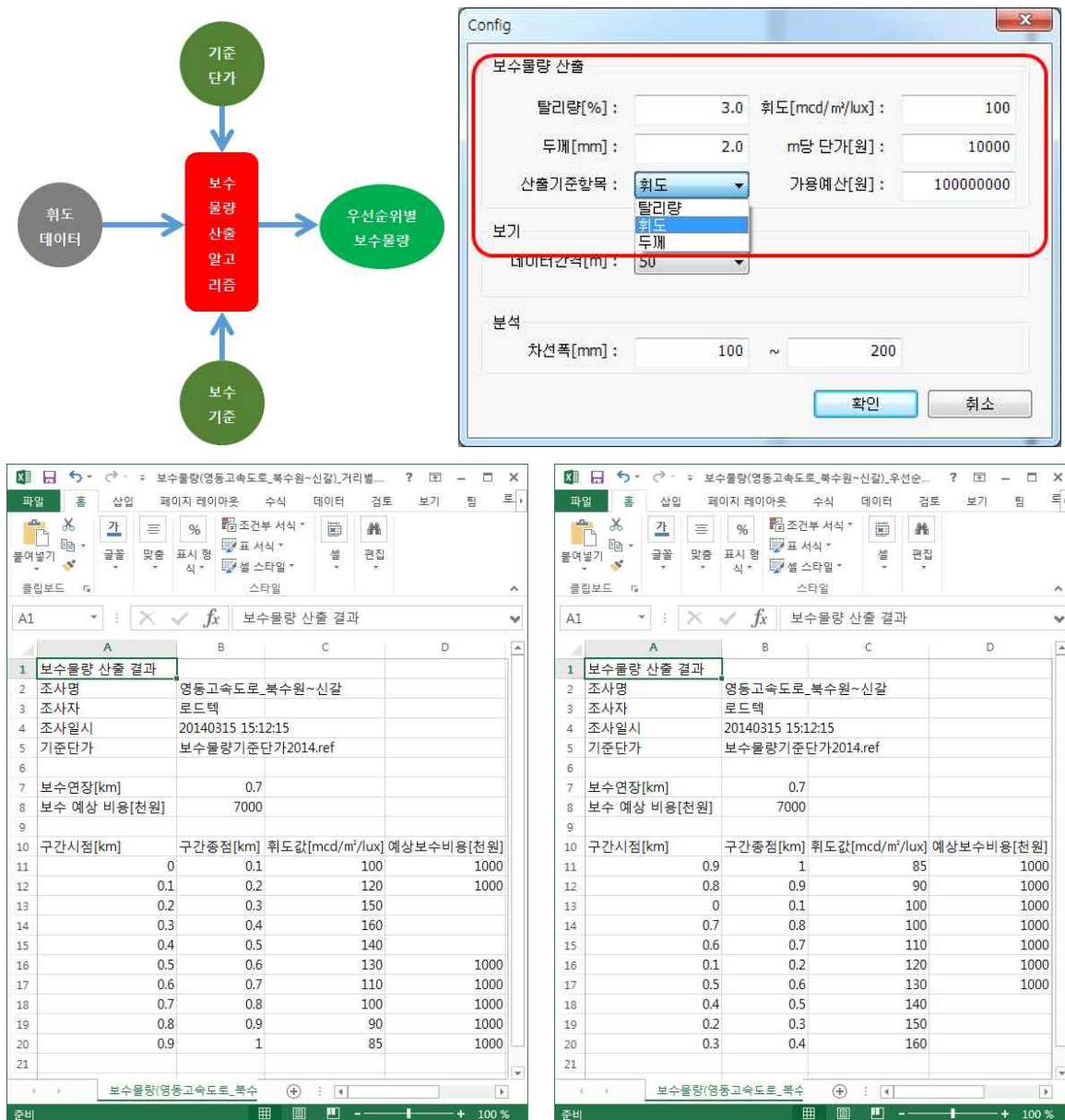


그림 3.75 보수물량 산출 알고리즘 및 산출 예

라. 보고서 생성 모듈

본 과업에서는 상세한 데이터 확인을 위한 엑셀 형식의 보고서를 생성할 수 있도록 하였으며, 해당지점의 GIS 데이터와 현황데이터를 함께 표기하여 보고서 확인을 용이하게 할 수 있도록 하였다. 개괄적인 상황을 원형 차트로 확인할 수 있도록 내부알고리즘을 구성하였다. 또한 차선관련 데이터를 수집, 가공, 분석하여 공공기관의 대표적 문서 포맷인 한글파일 형태로 출력하는 기능을 주 목표로 설정하였으며, 사용자 혹은 담당기관별 요구되는 형태로 제공될 수 있는 기본 알고리즘을 구성하였다. 기본적인 보고서 구성은 그림 3.76과 같다.



그림 3.76 보고서 생성 예

마. 주변영상 표출 모듈 개발

360도 전방위 카메라로 촬영된 주변 영상을 조회하려면 전용 뷰어가 필요하다. 이는 일반적인 이미지 뷰어에 360도 회전이 가능하도록 인터페이스를 제공해야 한다. 회전을 위한 인터페이스는 사용자에게 친숙한 키보드와 마우스를 이용하도록 주변영상 표출 모듈을 개발하였다.

- 마우스 왼쪽버튼 드래그 : 영상 회전
- 마우스 휠 : 영상 확대축소
- 키보드 좌우 방향키 : 영상 좌우 회전
- 키보드 상하 회전키 : 영상 상하 회전

본 과업에 적용한 360도 영상센서를 이용하여 측정위치 주변 시설 및 이정을 확인할 수 있

으며, 위치판단과 더불어 도로관련 안전시설의 상태 또한 확인이 가능하다.



그림 3.77 360도 전방위 영상 조회 모듈

바. 불량구간/정상구간 표시기능

분석 결과의 시인성을 높이기 위해 불량구간 및 정상구간을 노선과 차로별로 색상을 이용하여 구분한다. 그림 3.78과 같이 차로별 조사 궤적 및 분석결과 목록에 각 구간의 불량 여부를 표시하여 사용자로 하여금 조사 구간의 상태를 용이하게 파악할 수 있도록 구성하였다.



그림 3.78 불량구간 및 정상구간의 표시

사. Stand-alone 시스템으로 프로그램 구현

앞서 열거한 개별 개발 모듈을 통합하여 전체 유지관리 프로그램을 구성하였다. 각 모듈별 인터페이스를 추가시켰으며, 통합 시 발생할 수 있는 PC 자원 문제를 검토하여 프로그램을 구

성하였다. 유지관리 시스템에 포함될 모듈은 그림 3.79와 같다.



그림 3.79 Stand-alone 시스템 구성

웹 GIS맵을 이용할 때 해외 사용을 고려하여 구글맵을 이용한 조사계적 뷰어를 추가하여 구성하였다. 그림 3.80은 웹 GIS별 화면을 나타낸 것이다.



그림 3.80 다양한 웹 GIS 적용 예

앞서 개발/제작한 개별모듈을 통합하여 구성한 차선품질 유지관리 프로그램은 그림 3.81과 같다. 각각 기능을 갖는 개별창에 차선과 관련된 측정값(휘도, 차선두께, 탈리량 등)이 거리와 연동되어 표시가 되며, 해당위치를 확인할 수 있도록 웹 GIS와 연동되어 표시되도록 구성하였다. 이러한 위치정보 이외에 특정위치에서의 주변영상을 360도 전방위 영상을 조회할 수 있도록

록 구성하였다.



그림 3.81 차선품질 유지관리 프로그램

아. 개발 프로그램 적용 예

본 과제에서 개발한 차선토색 품질검사장치를 통해 획득된 데이터를 바탕으로 제작 프로그램의 유용성을 확인하기 위해 공용중인 도로구간(약 2.1km)에 대해 분석을 수행하였다. 조사구간의 황색차선에 대해 표 1.2의 경찰청 차선 재귀반사 휘도 재보수 권장 기준인 $70\text{mcd/m}^2/\text{lux}$, 그 외 두께는 2mm, 탈리량은 임의의 기준인 5%로 설정하여 분석을 수행하였다.

개발 프로그램에서 분석 및 출력된 결과보고서는 그림 3.82와 같다. 분석결과 재설치 권장 휘도 기준인 $70\text{mcd/m}^2/\text{lux}$ 미만 구간은 존재하지 않는 것으로 확인되었다. 두번째 분석 기준인 차선토색 두께를 기준으로, 시공 품질 기준인 2mm 미만을 적용한 결과 대부분의 구간에서 2mm 미만으로 나타났다. 마지막으로 탈리량을 기준으로 임의의 경계값인 5%를 적용한 결과 약 25%구간(500m)에서 상대적으로 많은 차선 탈리가 발생한 것으로 분석되었다. 이러한 분석 및 보고서 기능을 활용한다면 방대한 도로망에 설치된 차선토색 유지관리를 현재 보다 객관적이고 합리적으로 관리할 수 있을 것이라 판단된다.

차선도색 휘도(상태) 결과 보고서

■ 개요

- 프로젝트 명 : ○○○○구간 차선품질 평가
- 연장(m) : 0 ~ 2064
- 조사일시 : 2016-○○-○○

■ 판정기준

- 휘도[cd/m²/lux] : 70.00
- 두께[mm] : 2.00
- 탈리량[%] : 5.00

■ 종합결과

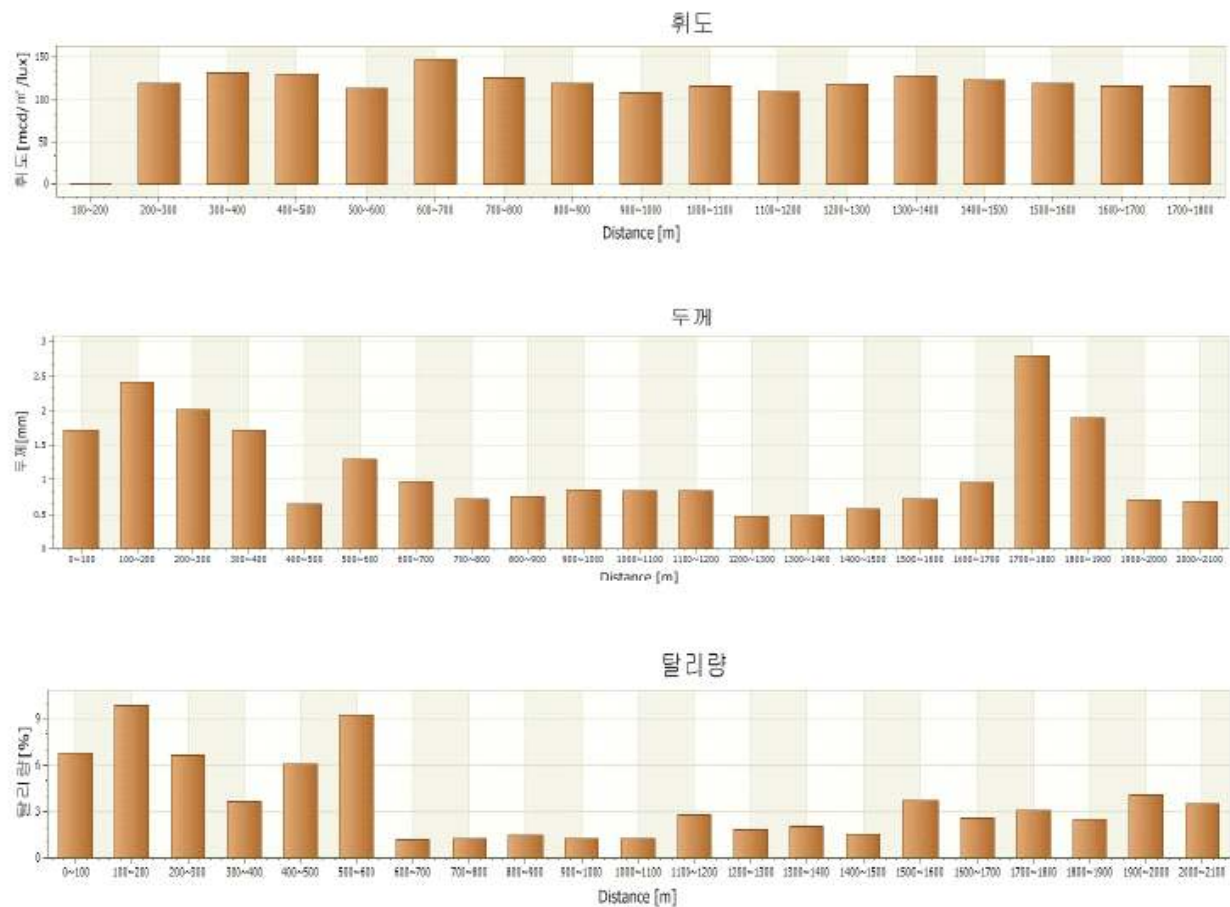


그림 3.82 차선도색 유지관리 프로그램 분석결과 예(계속)

■ 세부결과

구간[m]	휘도[cd/m2]	두께[mm]	탈리율[%]
0~100	117.00	1.71	6.75
100~200	119.00	2.41	9.86
200~300	132.00	2.03	6.62
300~400	130.00	1.71	3.65
400~500	113.00	0.65	6.07
500~600	148.00	1.30	9.24
600~700	126.00	0.97	1.13
700~800	119.00	0.72	1.25
800~900	108.00	0.75	1.49
900~1000	115.00	0.86	1.24
1000~1100	109.00	0.84	1.21
1100~1200	118.00	0.84	2.79
1200~1300	128.00	0.47	1.85
1300~1400	123.00	0.48	2.02
1400~1500	119.00	0.58	1.53
1500~1600	115.00	0.72	3.71
1600~1700	115.00	0.96	2.53
1700~1800	127.00	2.81	3.04
1800~1900	114.00	1.89	2.50
1900~2000	107.00	0.71	4.05
2000~2100	104.00	0.69	3.49

그림 3.82 차선도색 유지관리 프로그램 분석결과 예(계속)

■ 보수 단가 산출

휘도 기준(70 cd/m²/lux 이하 구간)

총보수길이[m]	단가[원]	총계[원]
0	2,300	0

두께 기준 (2mm 미만 구간)

총보수길이[m]	단가[원]	총계[원]
1,800	2,300	4,140,000

탈리량(%) 기준(5% 이상 구간)

총보수길이[m]	단가[원]	총계[원]
500	2,300	1,150,000

그림 3.82 차선도색 유지관리 프로그램 분석결과 예

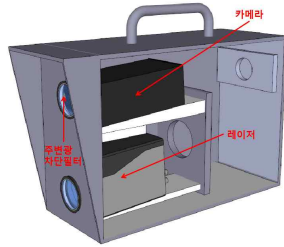
제4장. 목표 달성도 및 관련 분야 기여도

1. 목표 달성도

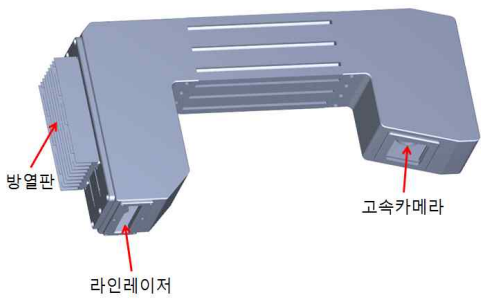
가) 목표 성과 달성도

구분	핵심성과 (level1)		단위성과 (level2)		최종 성과점검기준					
					질적 성과지표		목표치	측정방법	달성도(%)	가중치
차량탑재형 차선도색 품질 검사 장치 개발	A	차선도색 상태 측정기 개발	A-1	차선 도색상태 측정기 제작	①	사용광원	레저	시제품 확인	100	4
					②	측정 속도	≥12,500회/초	실측 비교	100	8
					③	가로 및 세로 분해능	≤2mm	실측 비교	100	6
					④	높이 분해능	≤0.5mm	실측 비교	100	6
					⑤	조사속도	≥80km/h	속도부하 테스트	100	6
					⑥	측정조건	주간/야간	현장검증	100	4
					⑦	스캔폭	≥50cm	실측비교	100	6
	B	차선도색 재귀반사 휘도 측정기 개발	B-1	차선도색 재귀반사 휘도 측정기 제작	①	입사각	88.76도	구성확인	100	4
					②	측정 각	1.05도	구성확인	100	4
					③	측정 속도	≥30회/초	현장검증	100	6
					④	측정 정 확도	≥90%	현장검증	100	6
					⑤	측정 조건	주간/야간	현장검증	100	4
					⑥	스캔 폭	1.1m	실측비교	100	4
					⑦	조사궤적 조사	GPS연동	현장검증	100	4
					⑧	측정 범위	10~1000mcd/m ² /lux	현장검증	100	4
					⑨	주변영상 획득	10m간격 영상획득	현장검증	100	4
	C	차선품질 유지관리 프로그램 개발	C-1	차선품질 유지관리 프로그램 제작	①	국내 웹 GIS맵을 이용한 조사위치 및 상태표시	1건	기능시연	100	2
					②	이력관리 기능	1건	기능시연	100	4
					③	차선 상태의 정상/불량 구간 표시기능	1건	기능시연	100	4
					④	보수물량 제시 기능	1건	기능시연	100	4
					⑤	보고서 생성 기능	1건	기능시연	100	2
					⑥	Stand-alone 시스템 구성	1건	기능시연	100	2
					⑦	주변영상 표현	1건	기능시연	100	2

(1) 차선도색 재귀반사 휘도 측정기 개발 (장비·장치)

관련 그림 / 사진																																				
정의(설명)		교통통제 없이 차선도색의 재귀반사 휘도를 측정하는 장비																																		
설정사유		차선도색 재귀반사 휘도 측정기의 국산화를 통해 국내 보급은 물론 성능향상을 통해 해외 시장에서의 경쟁력 확보																																		
목 적		- 차선 도색/재도색 후 준공 검사의 자료로 활용 - 차선 재도색 구간 선별 및 예산 편성의 기초 자료로 활용 - 교통차단 없이 차선 반사도 상태 판단 - 주행 안전 확보에 기여																																		
성능목표		<table><tr><th>구분</th><th>개발기술 목표성능</th><th>개발 성능</th></tr><tr><td>입사각</td><td>88.76도</td><td>88.76도</td></tr><tr><td>측정각(관찰각)</td><td>1.05도</td><td>1.05도</td></tr><tr><td>측정 속도</td><td>30회 이상/초</td><td>30회 이상/초</td></tr><tr><td>측정 정확도 (정지측정기 대비)</td><td>90% 이상</td><td>90% 이상</td></tr><tr><td>측정 조건</td><td>주간 및 야간</td><td>주간 및 야간</td></tr><tr><td>스캔 폭</td><td>1.1m</td><td>1.1m</td></tr><tr><td>조사궤적 조사</td><td>GPS 연동</td><td>GPS 연동</td></tr><tr><td>측정 범위</td><td>10 ~ 1000mcd/m²/lux</td><td>10 ~ 1000mcd/m²/lux</td></tr><tr><td>주변영상 획득</td><td>10m 마다의 전방영상 획득</td><td>10m 마다의 전방영상 획득</td></tr></table>					구분	개발기술 목표성능	개발 성능	입사각	88.76도	88.76도	측정각(관찰각)	1.05도	1.05도	측정 속도	30회 이상/초	30회 이상/초	측정 정확도 (정지측정기 대비)	90% 이상	90% 이상	측정 조건	주간 및 야간	주간 및 야간	스캔 폭	1.1m	1.1m	조사궤적 조사	GPS 연동	GPS 연동	측정 범위	10 ~ 1000mcd/m ² /lux	10 ~ 1000mcd/m ² /lux	주변영상 획득	10m 마다의 전방영상 획득	10m 마다의 전방영상 획득
구분	개발기술 목표성능	개발 성능																																		
입사각	88.76도	88.76도																																		
측정각(관찰각)	1.05도	1.05도																																		
측정 속도	30회 이상/초	30회 이상/초																																		
측정 정확도 (정지측정기 대비)	90% 이상	90% 이상																																		
측정 조건	주간 및 야간	주간 및 야간																																		
스캔 폭	1.1m	1.1m																																		
조사궤적 조사	GPS 연동	GPS 연동																																		
측정 범위	10 ~ 1000mcd/m ² /lux	10 ~ 1000mcd/m ² /lux																																		
주변영상 획득	10m 마다의 전방영상 획득	10m 마다의 전방영상 획득																																		
성과달성 책임자 (소속기관)		문형철(주식회사 로드텍)																																		
소요기간		2014.09.30. ~ 2016.09.29(2년0개월)																																		
핵심성과	양적성과	특허 출원 1건	SCI 논문 -	비SCI논문 -	S/W 1건	기타 시작품 1건																														
	질적성과	- 입사각 : 88.76도 - 측정각 : 1.05도 - 측정속도 : 30회/초 이상 - 측정정확도 : 90% 이상 - 측정조건 : 주간 및 야간 - 스캔폭 : 1.1m - 조사궤적조사 : GPS연동 - 측정범위 : 10~1000mcd/m²/lux - 주변영상 획득 : 10m간격 전방영상 획득																																		
	달성 확인방법	발주기관 주관 검증위원단 구성 및 현장테스트 수행																																		

(2) 차선도색 상태 측정기 개발 (장비·장치)

관련 그림 / 사진		 																												
정의(설명)		차선의 도색상태(박리 상태, 도색 높이)를 정량적으로 측정하는 장비																												
설정사유		차선의 두께 및 박리량 등으로 판단되는 차선의 상태를 측정하는 장비를 개발하여 차선품질 유지관리에 있어 기초 데이터 확보																												
목 적		- 차선 도색/재도색 후 준공 검사의 자료로 활용 - 차선 재도색 구간 선별 및 예산 편성의 기초 자료로 활용 - 교통차단 없이 차선 도색상태 판단 - 주행 안전 확보에 기여																												
성능목표		<table><tr><th>구분</th><th>개발기술 목표성능</th><th>개발 성능</th></tr><tr><td>광원</td><td>레이저</td><td>레이저</td></tr><tr><td>측정 속도</td><td>14,000회 이상/초</td><td>14,000회 이상/초</td></tr><tr><td>가로 및 세로 분해능</td><td>2mm 이하</td><td>2mm 이하</td></tr><tr><td>높이 분해능</td><td>0.5mm 이하</td><td>0.5mm 이하</td></tr><tr><td>조사 속도</td><td>100km/h 이상</td><td>100km/h 이상</td></tr><tr><td>측정 조건</td><td>주간 및 야간</td><td>주간 및 야간</td></tr><tr><td>스캔 폭</td><td>50cm 이상</td><td>50cm 이상</td></tr></table>					구분	개발기술 목표성능	개발 성능	광원	레이저	레이저	측정 속도	14,000회 이상/초	14,000회 이상/초	가로 및 세로 분해능	2mm 이하	2mm 이하	높이 분해능	0.5mm 이하	0.5mm 이하	조사 속도	100km/h 이상	100km/h 이상	측정 조건	주간 및 야간	주간 및 야간	스캔 폭	50cm 이상	50cm 이상
구분	개발기술 목표성능	개발 성능																												
광원	레이저	레이저																												
측정 속도	14,000회 이상/초	14,000회 이상/초																												
가로 및 세로 분해능	2mm 이하	2mm 이하																												
높이 분해능	0.5mm 이하	0.5mm 이하																												
조사 속도	100km/h 이상	100km/h 이상																												
측정 조건	주간 및 야간	주간 및 야간																												
스캔 폭	50cm 이상	50cm 이상																												
성과달성 책임자 (소속기관)		문형철(주식회사 로드텍)																												
소요기간		2014.09.30. ~ 2016.09.29(2년0개월)																												
핵심성과	양적성과	특허	SCI 논문	비SCI논문	S/W	기타																								
		출원 1건	-	-	1건	시작품 1건																								
	질적성과	- 광원 : 레이저 - 측정 속도 : 12,500회 이상/초 - 종방향(주행방향) 및 횡방향 분해능 : 2mm 이하 - 높이 분해능 : 0.5mm 이하 - 조사 속도 : 80km/h 이상 - 측정 조건 : 주간 및 야간 - 스캔 폭 : 50cm 이상																												
	달성 확인방법	발주기관 주관 검증위원단 구성 및 현장테스트 수행																												

(3) 차선품질 유지관리 프로그램 개발 (소프트웨어)

관련 그림 / 사진																														
정의(설명)		차선도색의 반사도 및 상태를 종합적으로 관리해주는 소프트웨어																												
설정사유		차선상태, 위치 및 이력 등을 종합적으로 관리하여 차선 유지보수 및 관리를 위한 관리자용 도구 제공																												
목 적		- 차선 도색의 반사도와 상태를 통합 관리 - 차선 도색에 관련한 이력 관리 - 차선 도색 보수물량 산출 및 보고서 생성 - 차선 도색/재도색 후 준공 검사의 자료로 활용 - 차선 재도색 구간 선별 및 예산 편성의 기초 자료로 활용 - 교통차단 없이 차선 반사도 상태 판단 - 주행 안전 확보에 기여																												
성능목표		<table><tr><th>구분</th><th>개발기술 목표성능</th><th>개발 성능</th></tr><tr><td>웹 GIS맵을 이용한 조사위치 및 상태표시</td><td>국내 웹 GIS 이용</td><td>국내 웹 GIS 이용</td></tr><tr><td>이력관리 기능</td><td>기 조사데이터 누적 기록</td><td>기 조사데이터 누적 기록</td></tr><tr><td>불량구간/정상구간 표시기능</td><td>노선, 차로별 생성</td><td>노선, 차로별 생성</td></tr><tr><td>보수물량 제시 기능</td><td>차선종류, 재료별 단가 반영</td><td>차선종류, 재료별 단가 반영</td></tr><tr><td>보고서 생성 기능</td><td>상태, 위치, 보수 물량 등</td><td>상태, 위치, 보수 물량 등</td></tr><tr><td>Stand-alone 시스템</td><td>관리자 독립 PC 운영 기능</td><td>관리자 독립 PC 운영 기능</td></tr><tr><td>주변영상 연동</td><td>10m 마다 획득된 전방영상 연동 표현</td><td>10m 마다 획득된 전방영상 연동 표현</td></tr></table>					구분	개발기술 목표성능	개발 성능	웹 GIS맵을 이용한 조사위치 및 상태표시	국내 웹 GIS 이용	국내 웹 GIS 이용	이력관리 기능	기 조사데이터 누적 기록	기 조사데이터 누적 기록	불량구간/정상구간 표시기능	노선, 차로별 생성	노선, 차로별 생성	보수물량 제시 기능	차선종류, 재료별 단가 반영	차선종류, 재료별 단가 반영	보고서 생성 기능	상태, 위치, 보수 물량 등	상태, 위치, 보수 물량 등	Stand-alone 시스템	관리자 독립 PC 운영 기능	관리자 독립 PC 운영 기능	주변영상 연동	10m 마다 획득된 전방영상 연동 표현	10m 마다 획득된 전방영상 연동 표현
구분	개발기술 목표성능	개발 성능																												
웹 GIS맵을 이용한 조사위치 및 상태표시	국내 웹 GIS 이용	국내 웹 GIS 이용																												
이력관리 기능	기 조사데이터 누적 기록	기 조사데이터 누적 기록																												
불량구간/정상구간 표시기능	노선, 차로별 생성	노선, 차로별 생성																												
보수물량 제시 기능	차선종류, 재료별 단가 반영	차선종류, 재료별 단가 반영																												
보고서 생성 기능	상태, 위치, 보수 물량 등	상태, 위치, 보수 물량 등																												
Stand-alone 시스템	관리자 독립 PC 운영 기능	관리자 독립 PC 운영 기능																												
주변영상 연동	10m 마다 획득된 전방영상 연동 표현	10m 마다 획득된 전방영상 연동 표현																												
성과달성 책임자 (소속기관)		문형철(주식회사 로드텍)																												
소요기간		2015.09.30 ~ 2015.09.29(1년0개월, 2년차)																												
핵심 성과	양적성과	특허	SCI 논문	비SCI논문	S/W	기타																								
		-	-	-	1건	-																								
	질적성과	- 국내 웹 GIS맵을 이용한 조사위치 및 상태 표시 : 국내 웹 GIS맵 이용 - 이력관리 기능 : 기 조사데이터 누적 기록 및 이력 비교 - 차선 상태의 정상구간/불량구간 표시기능 : 노선, 차로별 생성 - 보수물량 제시 기능 : 차선종류, 재료별 단가 반영한 보수물량 제시 - 보고서 생성 기능 : 상태, 위치, 보수 물량을 포함한 보고서 생성 - Stand-alone 시스템 : 관리자 독립 PC 운영 기능 - 주변영상 연동 : 10m마다 획득된 전방영상 연동 표현																												
	달성 확인방법	- 발주기관 주관 검증위원단을 구성 프로그램 기능 구현여부 확인																												

2. 관련 분야 기여도

본 과업에서 개발된 차량탐재형 차선도색 품질검사장치를 현 유지관리 업무 적용에 적용할 경우 예상되는 각 분야별 기여도를 요약하면 다음과 같다.

(가) 공공 분야

- 지속적인 차선상태를 관리할 수 있는 기반 제공으로 도로이용자 안전성 향상.
- 공공재산인 도로 부속시설의 정량적 평가기술제공으로 자산(Asset)가치 유지를 위한 기본기술 제공.

(나) 기술 분야

- 교통 통제 없이 차선 휘도 및 도색상태를 신속하게 조사 할 수 있는 응용기술개발.
- 고속 주행 중 변위취득을 위한 기초 알고리즘 확보로 타 응용분야 적용가능(도로 표면상태 등).
- 위치자료와 웹GIS를 연계한 타 도로시설물관리에 활용 가능.

(3) 학술 분야

- 공용중인 도로에서 차선 재료 및 공법에 따른 휘도 및 상태 평가에 활용가능.
- 차선관련 신 재료 성능평가에 활용.
- 차선재료, 교통량, 환경(기후), 교통특성 등을 반영한 차선 내구성 특성분석에 활용.

(4) 경제 분야

- 외산제품의 수입 대체 및 기능적 우월성 확보

구분(경쟁력)	외산 제품	개발 제품	비 고
가격 측면	1억8천~2억2천	1억6천 ~ 2억	차선 휘도측정기
기능 측면	-GPS위치 측정 -조사속도:0~150kph -조사환경:주야간 -측정범위:1.0~1.1m	-GPS위치 측정 -조사속도:0~120kph -조사환경:주야간 -측정범위:1.1m -웹GIS 연계 -차선도색유지관리프로그램제공	외산장비 동등 성능제공
운영 측면	-차선도색 유지관리 프로그램 부재	-웹GIS를 활용, 프로그램 유지관리 비용이 필요 없는 차선도색 유지관리 프로그램 제공	차선도색 유지관리 프로그램 제공
	-운영자 자체 교/검정	-운영자자체 및 제조사 정밀 교/검정	제조사 교검정으로 신뢰성확보
기 타	-	-차선 두께 및 도색상태(탈리량) 산출기능 모듈 (8천~1억)	외산장비에 없는 차선두께, 탈리량 산출기능

- 방대한 도로망의 차선상태를 신속하게 전수조사 가능함으로써 합리적인 보수필요 구간설정 가능
- 공용도로의 정기적 조사를 통한 차선 품질향상, 유지관리 비용의 효율적 분배에 기여

(5) 기타 분야

- 도로포장유지관리 관련 국내 기술 확보
- 국내 활용실적을 기반으로 아시아 개발 국가 시장 확보 가능
 - 국외 도로포장 조사사업에 향후 추가 조사항목 선정 추진
 - 국외 도로안전진단 프로그램인 iRAP(International Road Assessment Program)사업 참여 추진(그림 4.1)

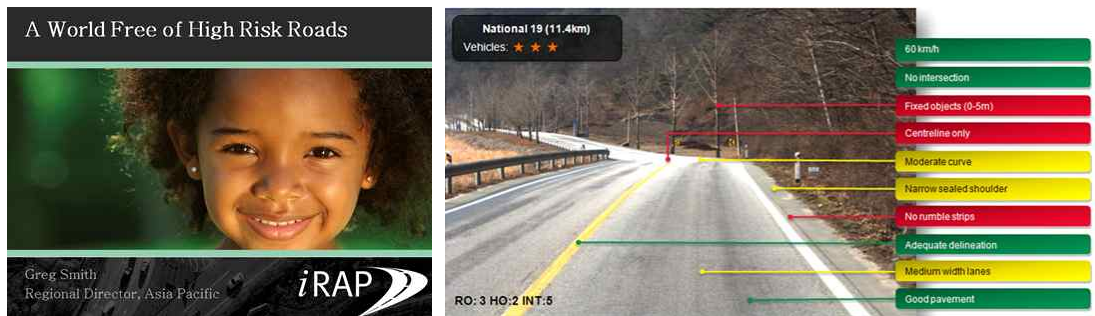


그림 4.1 iRAP(International Road Assessment Program)

제5장. 연구개발성과의 활용계획

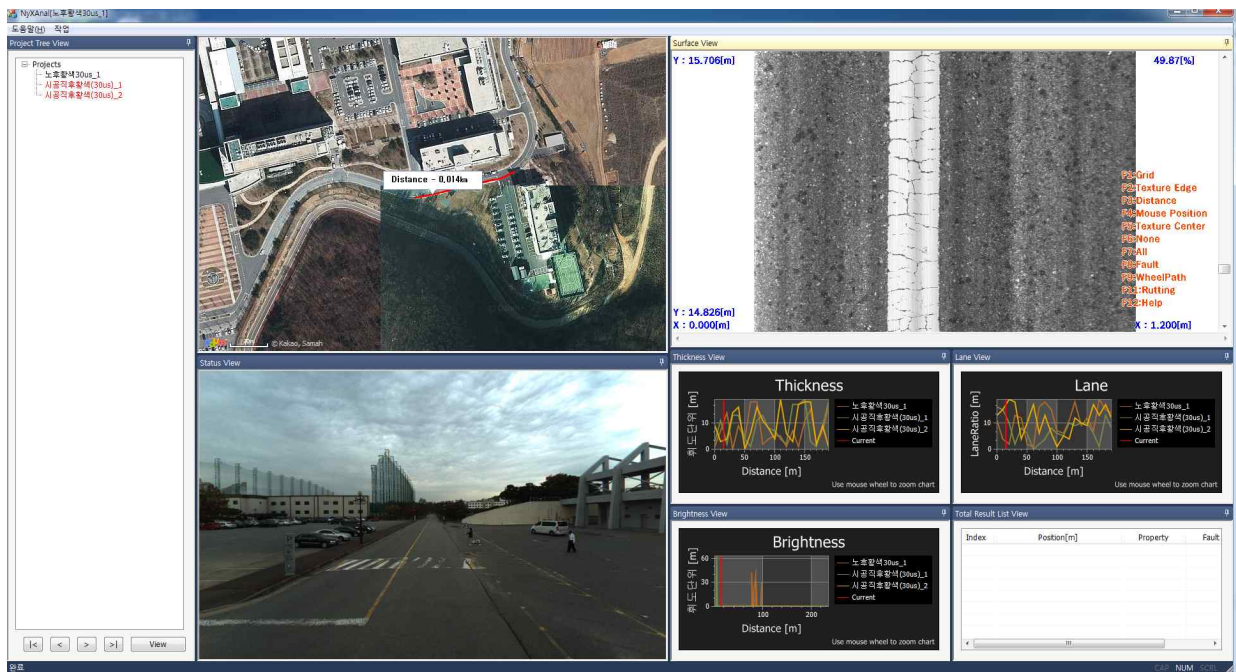
국내·외 일반 휘도측정기는 일부 국한된 지점의 재귀반사 휘도만 측정할 수 있는 단점이 있다. 또한 국외 차량 탑재형 차선재귀반사 휘도 측정기는 이동 중 단순 차선 휘도 측정 기능만 탑재되어 있으나, 본 과제에서는 재귀반사 휘도와 물리적인 차선도색상태까지 확인 할 수 있는 영상+변위 측정부를 포함하게 된다. 또한 방대한 차선 상태를 용이하게 조회/분석 할 수 있는 S/W도 제작하여 효율적인 차선관리를 할 수 있는 전체적 시스템을 그림 5.1과 같이 개발하였다. 이러한 통합적인 시스템으로 인해 방대한 도로망의 차선관리를 체계적으로 관리할 수 있는 기반을 제공하게 된다.



(a) 차선 휘도측정기



(b) 차선 도색상태 조사기



(c) 차선 유지관리 프로그램

그림 5.1 개발 제품 현황

개발 장비의 수요는 표 5.1과 같이 예상된다. 고속도로 및 국도이외에 5대 광역시 도로관리 부처에서 수요가 추가적으로 발생된다면, 5년 이내 최소 15~20대 정도의 장비수요가 발생할

것으로 예상된다.

표 5.1 도로관리기관 현황(출처 국토관리청/도로공사 홈페이지)

기관	지부	관리 연장(km)	관리 연장별 예측수량	예측수량
국토관리청	서울지방 국토관리청	1,733.50	1EA/2000KM	1
	부산지방 국토관리청	4,162.70		2
	대전지방 국토관리청	2,363.00		1
	익산지방 국토관리청	3,506.00		2
	원주지방 국토 관리청	1,947.90		1
	소계	13,713.10		7
한국 도로공사	수도권 본부	525.20	1EA/500KM	1
	강원 본부	570.20		1
	대전충청본부	495.90		1
	전북 본부	519.04		1
	광주전남 본부	569.02		1
	대구경북 본부	596.70		1
	부산경남 본부	515.60		1
	소계	3,791.66		8
총계		17,504.76		15

가. 연구결과의 활용방안

- 본 차선도색 품질검사장비는 정부주도 연구개발 사업의 성공적 수행결과임을 강조하여 본 개발장비의 수요가 예상되는 유관기관(고속도로 지역본부, 각 국도 관리청 및 지방자치단체 도로관리부서등)에 적극적 홍보 실시.



그림 5.2 개발 제품의 적극적 홍보 방안

- 현재 시행중인 고속도로 및 국도 포장관리시스템(PMS)과 연계방안을 추진하여 단기 조사
가 아닌 지속가능한 차선품질평가가 이루어 질 수 있도록 추진.
- 차선토색업체의 품질향상을 위한 제품별 장기공용성 평가 및 자료 제공.
- 공항 포장의 다양한 포장도색평가에 응용 개선하여 신규시장 진출.
- 기존 도로포장조사장비 운영 기관의 조사장비 교체시 차선토색품질검사장치 추가 제안

표 5.2 국내 도로유지관리 조사차량 보유기관 및 수량

도로유지관리관련 조사장비 운영기관	최초 도입시기	교체 및 신규장비 도입 예정시기*	보유 대수
한국건설기술연구원	2008	2017	2
	2014	2023	
한국도로공사	2010	2016	2
	2013	2019	
도로교통공단	2010	2018	2
	2013	2021	
교통안전공단	2013	2018	1
서울특별시	2013	2019	1
한국공항공사	2014	2020	1
대한민국 공군	2014	2024	1
기업 A	2012	2018	6
	2015	2020	
합 계			16

*각 기관별 도로유지관리 관련 조사장비 장비교체 주기 추정 년도



그림 5.3 국내 운용중인 도로관련 유지관리 조사차량 예

나. 기대성과 및 파급효과

(1) 과학기술적 측면

- 교통 및 도로관련 개별기술의 융합 개발제품인 차선토색품질평가 검사장치는 정밀 측정이
필요한 다른 산업분야에 용이하게 적용될 수 있는 융복합 기술임.

(2) 사회·경제적 측면

- 국내 건설시장환경이 신설에서 유지관리로 변화하면서 도로안전시설관리측면에서 조사자료에 근거한 객관적 상태파악 및 평가 될 수 있는 시스템 제공.
- 체계적인 도로교통안전시설 유지관리 기반 구축으로 우리나라 교통사고 사망자수 감소 기대.

(3) 정책적 측면

- 교통사고로 야기되는 사회적 비용 증가 및 교통안전에 대한 국민관심 증가로 사고예방을 위한 범 국가적 적극적 개선 대책에 기여함.

다. 연구성과의 등록·기탁 의향

본 과제 수행을 통해 창출한 논문, 특허, 보고서원문, 연구기자재, 기술요약정보, 생명자원, 화합물, 소프트웨어 등을 「국가연구개발사업의 관리 등에 관한 규정」 제25조의 제13항에 따른 연구성과 분야별 관리·유통 전담기관에 등록 또는 기탁에 동의하여 해당사항에 필요한 수행절차등에 적극 협조 동의.

라. 기타

과제 산출물인 “차량탐재형 차선도색 품질 검사장치”를 단순 장비판매에 그치는 것이 아니라 구매기관과 적극적 의사소통을 통해 응용 및 확장된 신규 제품개발을 공동으로 수행하고 지속적인 결과물의 성능개선 및 제품으로써의 기술 및 가격경쟁력을 확보하여 국내 뿐 아니라 세계적인 경쟁력을 갖춘 제품으로 공동사업을 추진하는 것이 바람직 할 것으로 판단됨.

제6장. 연구 과정에서 수집한 해외 과학기술 정보

- 차 례 -

- ☐ Long Term Pavement Marking Practices(NCHRP Synthesis 306)
- ☐ Road marking materials – Road marking performance for roadusers(prEN 1436 rev)
- ☐ TestCertificate of the suitability of the dynamic retroreflectometer ZDR 6020 for the dynamic measurement of the coefficient of retroreflected luminance RL of road markings
- ☐ RSS 22 Road markings – Traffic standards and guidelines 2003/2004 survey
- ☐ LASERLUX®:AUTOMATED REAL TIME PAVEMENT MARKING RETROREFLECTIVITY MEASUREMENTS
- ☐ Zehntner mapping and data analysis software – Mapping tools

NCHRP

SYNTHESIS 306

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Long-Term Pavement Marking Practices

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
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NCHRP SYNTHESIS 306

Long-Term Pavement Marking Practices

A Synthesis of Highway Practice

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Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

*By Staff
Transportation
Research Board*

This synthesis report will be of interest to local and state transportation agencies as well as to the pavement marking industry that works with them in long-term pavement marking practices. This report documents the current and best practices for managing pavement marking systems, identifies future needs, and addresses driver needs and methods of communicating information to drivers, selection criteria (e.g., reflectivity, pavement service life, wet weather performance), materials (e.g., color, durability, cost), specifications, construction practices, and inventory management systems. It also explores several challenges facing agencies, including funding, nighttime visibility in rain and fog, quality control after installation, and the shortage of quality labor, and discusses new technologies, methods of performance measurement, and environmental constraints.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board contains information derived from survey responses from 61 state, province and territory, county, and city transportation

agencies and private companies in the United States and Canada to document long-term pavement marking practices and research, and discusses the many different practices among agencies due to variations in structure, policies, and climate. Three types of surveys were distributed: transportation agency, pavement marking equipment/material manufacturers/distributors, and retroreflectometer manufacturers/distributors. The *Manual on Uniform Traffic Control Devices for Streets and Highways* was used as the guiding document.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the available information was assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the author's research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

1	SUMMARY
5	CHAPTER ONE INTRODUCTION Objectives and Scope, 5 Background, 5 Report Organization, 7
8	CHAPTER TWO PROCESS FOR MAKING DECISIONS ON PAVEMENT MARKINGS Deciding Where to Put Pavement Markings, 8 Selecting Pavement-Marking Materials, 8 Deciding When to Remove or Replace Pavement Markings, 11 Summary, 12
13	CHAPTER THREE DRIVER NEEDS, RETROREFLECTIVITY REQUIREMENTS, AND INFORMATION THROUGH WORD AND SYMBOL MARKINGS Information Needed by Drivers, 13 Minimum Retroreflectivity for Nighttime Visibility of Pavement Markings, 15 Information Through Pavement Word and Symbol Markings, 20 Summary, 26
28	CHAPTER FOUR TRAFFIC CRASHES AND PAVEMENT MARKINGS Traffic Crashes and Related Statistics, 28 Safety Evaluation, 32 Safety of Marking Crews, 33 Summary, 33
34	CHAPTER FIVE MATERIAL SELECTION CRITERIA Material Selection Factors, 34 Line Width and Patterns, 36 Summary, 38
39	CHAPTER SIX SPECIFICATIONS AND CONSTRUCTION PRACTICES Specifications for Pavement Markings, 39 Specifications Used by Transportation Agencies, 39 Construction Requirements, 40 Color Specifications, 40 Durability Specifications, 44 Retroreflectivity Specifications, 46 Construction Practices, 49 Summary, 50

52	CHAPTER SEVEN	PAVEMENT MARKING MATERIALS Environmental Considerations, 52 Types of Pavement Markings, Service Life, Cost, and Life-Cycle Cost, 53 Other Materials, 67 Summary, 68
70	CHAPTER EIGHT	INVENTORY MANAGEMENT SYSTEM FOR PAVEMENT MARKINGS Agency Experience with an Inventory Management System, 70 Elements of an Inventory Management System, 70 Summary, 72
73	CHAPTER NINE	PERFORMANCE EVALUATION Performance and Evaluation Practices, 73 Correlation of Retroreflectometers, 75 Incorporating the Geographical Information System, 82 Considerations for Selecting a Hand-Held or Mobile Retroreflectometer, 82 Summary, 83
84	CHAPTER TEN	CONCLUSIONS
88	REFERENCES	
93	DEFINITIONS OF PAVEMENT-MARKING MATERIALS	
95	APPENDIX A	SURVEY QUESTIONNAIRE
103	APPENDIX B	SURVEY RESPONDENTS
104	APPENDIX C	ANNUAL PAVEMENT MARKING EXPENDITURE AND HIGHWAY MILEAGE IN YEAR 2000
106	APPENDIX D	EXAMPLES OF PAVEMENT MARKING MATERIAL SELECTIONS AND PLACEMENT GUIDELINES
114	APPENDIX E	EXAMPLE PRESCRIPTIVE SPECIAL PROVISION FOR EPOXY PAVEMENT MARKINGS USED BY THE MARYLAND STATE HIGHWAY ADMINISTRATION
119	APPENDIX F	EXAMPLE PERFORMANCE-BASED SPECIAL PROVISION FOR WATERBORNE PAINT USED BY THE VIRGINIA DEPARTMENT OF TRANSPORTATION

123	APPENDIX G	EXAMPLE WARRANTY PROVISIONS SPECIAL PROVISION FOR DURABLE PERMANENT PAVEMENT MARKINGS USED BY THE OREGON DEPARTMENT OF TRANSPORTATION
133	APPENDIX H	EXAMPLE SPECIFICATIONS FOR GLASS BEADS
137	APPENDIX I	EXAMPLE SPECIFICATIONS FOR RAISED PAVEMENT MARKERS
146	APPENDIX J	EXAMPLE TEST METHOD FOR QUALITY CONTROL TESTING OF PAVEMENT MARKINGS USED BY THE VIRGINIA DEPARTMENT OF TRANSPORTATION



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James Migletz was responsible for the preparation of this report. Mr. Migletz passed away shortly after completing his work on this report. We wish to acknowledge his dedication in completing this comprehensive study, and his lifetime of outstanding achievement as a transportation researcher and engineer.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of J. Stuart Bourne, Traffic Control/Marketing Engineer, North Carolina Department of Transportation; Benjamin H. Cottrell, Jr., Senior Transportation Research Scientist, Virginia Transportation Research Council; Gene H. Hawkins, Jr., Division Head, Texas A&M System, Texas Transportation Institute; Dal J. Hawks, Region Four Director, Utah Department of Transportation; Neil A. Hodson, 3M Traffic Control Materials Division, 3M Center, St. Paul; Debby Kozol, P.E., Traffic Operations Engineer, Bureau of Highway Operations, Madison; Frank N. Lisle,

Engineer of Maintenance, Transportation Research Board; Michael E. Robinson, Highway Engineer, Federal Highway Administration; Peter F. Rusch, State Traffic Engineer, Wisconsin Department of Transportation; and Samuel C. Tignor, McLean, Virginia.

This study was managed by Stephen Maher and Jon Williams, Managers, Synthesis Studies, who worked with the consultant, the Topic Panel, and the Project 20-5 Committee in the development and review of the report. Assistance in project scope development was provided by Donna Vlasak, Senior Program Officer. Don Tippman was responsible for editing and production. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

Crawford F. Jencks, Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-5 Committee and the Synthesis staff.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

LONG-TERM PAVEMENT MARKING PRACTICES

SUMMARY

An important means of communicating information to drivers is through pavement markings. Transportation agencies use longitudinal pavement markings, pavement markers, and word and symbol markings to provide long-term markings for their highway systems. Sixty-one state, province and territory, county, and city agencies and private companies in the United States and Canada were surveyed to document long-term pavement marking practices and research. There are many differences in practices among transportation agencies because of variations in their structure, policies, and climate. In addition, because of changes in technology, driver needs, and environmental constraints, there are many more materials being used and evaluated than in the past. Furthermore, new technologies and methods for measuring the performance of pavement markings have been and continue to be developed, making the scope of the topic area quite broad.

In this report, the current and best practices for pavement markings are highlighted and future needs are identified. The relationship of the practice to the *Manual on Uniform Traffic Control Devices* (MUTCD) is documented. In addition, the following issues are addressed:

- The process for making decisions on pavement markings,
- Driver needs and ways of communicating information to drivers,
- Traffic crashes related to pavement markings,
- The criteria for selecting materials,
- Specifications and practices,
- Materials,
- Inventory management systems, and
- Performance evaluations using retroreflectometers.

The top four problems and challenges facing transportation agencies and the pavement marking industry are finding the funding for pavement marking programs, nighttime visibility in rain and fog, quality control when markings are installed, and a shortage of quality labor. The estimated total money spent on pavement markings in the year 2000 by the 50 state transportation agencies, 13 Canadian provinces and territories, U.S. counties, and U.S. cities was \$1,548,616,821 on 6 148 088 centerline-km (3,818,688 centerline-mi) of highways. The MUTCD specifies and recommends where centerline, lane line, and edge line markings are to be provided based on the type of roadway, the width of traveled way, and the average daily traffic. Some agencies exceed the recommendations of the MUTCD.

Results of research on pavement marking material color, retroreflectivity, and durability are used to improve marking programs. Policies and specifications guide material selection, placement, and evaluation.

Eight state agencies have summarized guidelines for the selection of materials based on 11 factors, the most common being type of line, pavement surface, traffic volume, and type of street and highway. Centerlines and lane lines are more likely to receive durable markings

than edge lines. Interstate highways, freeways, and expressways are more likely to receive durable markings than two-lane, two-way highways. Highways with higher traffic volumes and pavements in new or good condition are more likely to receive durable materials. Most agencies specify the standard line width as 100 mm (4 in.). Wider markings are used to provide greater emphasis.

Drivers encounter difficulties in nighttime guidance because pavement markings often disappear, especially during rain and fog. Increasing retroreflectivity can increase pavement marking visibility and preview distances. A preview time of 2 s was found to be the minimum acceptable limit on roads with properly maintained pavement markings and retroreflective raised pavement markers (RRPMs). At 90 km/h (55 mph), delineation must be visible at least 49 m (162 ft) ahead. A preview time of 3 s is recommended to provide long-range guidance information. At 90 km/h (55 mph), delineation must be seen at least 74 m (243 ft) ahead.

Older drivers require more light to see delineation and are slower to react. It appears that older drivers cannot be accommodated at all speed levels with pavement markings. However, the addition of RRPMs makes it possible to accommodate most drivers.

The standard for measuring pavement-marking retroreflectivity is the 30-m (98.4-ft) geometry. The American Society for Testing and Materials specifies that a new marking is required to have a minimum initial retroreflectivity of 250 millicandelas per square meter per lux ($\text{mcd}/\text{m}^2/\text{lux}$) for white markings and 175 $\text{mcd}/\text{m}^2/\text{lux}$ for yellow markings. Some state agencies require higher initial retroreflectivity, depending on the material, whereas others do not have any initial retroreflectivity requirements.

The FHWA has developed candidate MUTCD criteria for retroreflectivity of pavement markings, but no such criteria have yet been approved and implemented as policy. The criteria are based on speed, road class, color of line, and presence or absence of roadway lighting or RRPMs. The FHWA sponsored research to determine the impact of the minimum retroreflectivity values on a typical state agency. To meet the minimum values, a typical state agency may have to replace as much as 25% of markings in the fall and 45% in the spring. It may be necessary to increase the amount of money spent annually on pavement markings from \$2.4 to \$3.5 million. However, the increase would be offset by a reduction of fewer than two fatalities.

Pavement marking retroreflectivity under wet pavement conditions averaged only 46% of the comparable values under dry pavement conditions. For example, to achieve a wet-pavement retroreflectivity of 150 $\text{mcd}/\text{m}^2/\text{lux}$, the marking would need a dry-pavement retroreflectivity of 326 $\text{mcd}/\text{m}^2/\text{lux}$.

A scanning tour of European pavement marking practices recommended that all-white pavement markings and tiger tail ramp markings both be studied for U.S. implementation. Chevron markings spaced at 40 m (131 ft) to indicate the proper vehicle spacing reduce tailgating and accidents and have an 80:1 benefit-cost ratio.

The long-term trend in the United States and Canada shows reductions in traffic fatalities. U.S. traffic fatalities decreased 12% from 1988 through 1998, while traffic fatalities in Canada decreased 29%. However, over the 10-year period from 1991 through 2000 traffic fatalities in the United States remained fairly constant, averaging 41,256 fatalities per year (ranging from 39,250 to 42,056). The variation in fatalities appears to be random.

Pavement markings can reduce traffic crashes occurring under darkness. Fatal crashes in the United States are more likely to occur under darkness than injury or property-damage-only crashes. In 1999, 23% (1,449,000) of all traffic crashes in the United States occurred under darkness during normal weather. An FHWA study of pavement marking retroreflectivity showed an 11% reduction in nonintersection traffic crashes occurring at night on dry pavements. In 1999, 4% (270,920) of all crashes occurred under darkness during conditions of rain and/or fog. The FHWA study of pavement marking retroreflectivity did not show a reduction in nonintersection nighttime crashes on wet pavements.

The three types of pavement marking specifications are prescriptive/material, performance-based, and warranty provisions. Of the agencies surveyed, 75% were satisfied with their specifications. Most agencies are confident that they are receiving good materials, but less sure that the application of the markings is adequate. Agencies are starting to use more performance-based and warranty provisions contracts to place more responsibility for quality markings on contractors.

A number of methods are used for preparing the pavement surface for material application including sweeping; air, sand, or water blasting; use of solvents; grinding; and scraping. Air cleaning is often done with a nozzle on the striper located immediately ahead of nozzles that spray the marking material. Surface preparation becomes more complicated when using durable materials and on portland cement concrete pavement. Grinding is the most common method of removing markings. Markings containing hazardous materials, such as lead or chromium, are required be taken away when removed from the pavement.

Sixteen types of materials are being used for longitudinal markings, with state agencies using the largest variety. There has been a shift away from using conventional solvent paint with a high volatile organic compound content. Waterborne paint is the most common material and is used by 78% of the agencies, followed by thermoplastic at 69%. Waterborne paint is striped on almost 60% of the total mileage at a cost of 17% of the total money spent on pavement markings. Thermoplastic is striped on almost 23% of the total mileage at a cost of 35% of the money spent on pavement markings. Durable markings are being used to increase the service life of pavement marking systems. The trend is to have contractors apply durable markings, many of which require specialized equipment and highly trained workers.

The service life of longitudinal pavement markings varies by color of line and type of pavement surface. At a threshold value of 100 mcd/m²/lux, white lines have a service life of 34 months, which is 42% greater than the 24-month service life of yellow lines. The longer service life of white materials shows a benefit of an all-white system of pavement markings. Lines on asphaltic concrete pavement have a service life of 33 months, which is 27% greater than the 26-month service life of lines on portland cement concrete pavement. However, service life is highly variable and is affected by material, traffic volume, and other factors.

The service lives, costs, and life-cycle costs of longitudinal pavement markings vary considerably by the type of marking material. The cost of traffic delay because of striping operations and measurement of retroreflectivity can add significantly to the life-cycle cost of longitudinal markings. New products are coming on the market that can improve nighttime visibility in adverse weather and have the potential to improve traffic safety.

Acceptable retroreflectivity in an RRPM is dependant on cumulative traffic volume. Retroreflectivity may last for as little as 6 months on a high-volume freeway with truck traffic. The more durable and expensive RRPMs become cost-effective when average annual daily traffic reaches 10,000 veh/day per lane.

An inventory management system tracks the service life of pavement markings by storing information on installations, inventory, retroreflectivity, specific action steps, costs, and suppliers in a database. The goal of implementing an inventory management system is to enable transportation agencies to select cost-effective markings with increased service lives that will reduce the cost of marking a highway system. Longer-lasting retroreflective markings that reduce traffic crashes will be the benefit of such a system. One-half of the surveyed agencies have implemented or are planning to implement an inventory management system. At this time, agencies have not had enough experience with inventory management systems to realize any benefits.

The FHWA has been promoting techniques to inspect and evaluate pavement markings. Some agencies have specifications and guidelines addressing performance evaluations. New markings are usually inspected within 1 month after placement, but there is no universally accepted schedule for inspecting existing markings. Training courses are available to enable personnel to become more proficient with inspection procedures. Agencies are using 30-m (98.4-ft) retroreflectometers to evaluate retroreflectivity. Field tests of four hand-held and two mobile retroreflectometers showed that measurements collected with these instruments were within an 8% range, which is a good correlation.

Retroreflectivity data were incorporated into a geographical information system to evaluate pavement-marking life cycles and develop predictive models for materials. The ability to efficiently review and query retroreflectivity data by type of pavement marking, condition, location, and jurisdiction benefits both the administrative and operational areas of a transportation agency.

Mobile and hand-held retroreflectometers each have advantages and disadvantages. Agencies selecting a hand-held or mobile retroreflectometer should consider initial capital cost, maintenance costs, manpower resources, required data accuracy, equipment reliability, and compliance with current testing standards.

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English version

Road marking materials - Road marking performance for road users

Produits de marquage routier - Performances des marques
appliquées sur la route

Straßenmarkierungsmaterialien - Anforderungen an
Markierungen auf Straßen

This draft European Standard is submitted to CEN members for unique acceptance procedure. It has been drawn up by the Technical Committee CEN/TC 226.

If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

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Contents

	page
Contents.....	2
Foreword.....	3
Introduction	4
1 Scope	5
2 Normative references	5
3 Definitions, symbols and abbreviations.....	5
4 Requirements	6
Annex A (normative) Measurement method for the luminance coefficient under diffuse illumination	
Qd	14
A.1 General requirements for measurement	14
A.2 Laboratory measurement.....	15
A.3 Portable instruments	16
Annex B (normative) Measurement method for the coefficient of retroreflected luminance R_L	23
B.1 General requirements for measurement	23
B.2 Laboratory measurement.....	24
B.3 Portable instruments	27
B.4 Vehicle mounted equipment.....	31
B.5 Condition of wetness.....	32
B.6 Condition of rain	32
Bibliography	34

Foreword

This document (prEN 1436:2004) has been prepared by Technical Committee CEN/TC 226 “Road equipment”, the secretariat of which is held by AFNOR.

This document is currently submitted to the UAP.

This document will supersede EN 1436:1997.

Annexes A and B are normative.

Introduction

Road markings together with road studs form the means for horizontal signalization.

Road markings include longitudinal markings, arrows, transverse markings, text and symbols on the surface of the highway etc.

Road markings can be provided by the application of paint, thermoplastic materials or cold hardening materials, pre-formed lines and symbols or by other means.

Most road markings are white or yellow, but in special cases other colours are used.

Road markings are either permanent or temporary. The functional life of temporary road markings is limited by the duration of the road works. For permanent road markings it is best for reasons of safety to have a functional life that is as long as possible.

Road markings can be applied with or without the addition of glass beads. With glass beads the retroreflection of the marking is achieved when the marking is illuminated by car headlamps.

The retroreflection of a marking, in wet or rainy conditions, can also be enhanced by special properties. The properties can be produced by surface texture (as with structured markings), large glass beads or other means. In the case of surface texture, the passage of wheels can produce acoustic or vibration effects.

Road markings with special properties as mentioned above are called 'type 2' road markings and are intended to comply with one of the classes RW1 to RW4 and/or one of the classes RR1 to RR4, refer to Tables 4 and 5 of 4.3. Road markings without such special properties are called 'type 1' road markings and are not intended to comply with the above-mentioned classes.

1 Scope

This standard specifies the performance for road users of white and yellow road markings, as expressed by their reflection in daylight or under road lighting, retroreflection in car headlamp illumination, colour and skid resistance.

2 Normative references

This European Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 13036-4, *Road and airfield surface characteristics - Test methods - Part 4: Method for measurement of slip/skid resistance of a surface - The pendulum test*

IEC 60050-845: 1987, *International Electrotechnical Vocabulary – Chapter 845 : Lighting*

NOTE: CIE Publication 17.4 International Electrotechnical Vocabulary is identical to IEC 60050-845.

ISO/CIE 10526, *CIE standard illuminants for colorimetry*

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in IEC 60050-845 and the following apply.

3.1

luminance coefficient under diffuse illumination (of a field of a road marking) Q_d ($\text{mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$)
quotient of the luminance of the field of the road marking in the given direction by the illuminance on the field.

3.2

luminance factor (of a field of a road marking, in a given direction, under specified conditions of illumination) β (unit: 1)
ratio of the luminance of the field of the road marking in the given direction to that of a perfect reflecting diffuser identically illuminated.

NOTE This definition is slightly adapted as compared to the definition of IEC 60050-845.

3.3

coefficient of retroreflected luminance (of a field of a road marking) R_L ($\text{mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$)
quotient of the luminance L of the field of the road marking in the direction of observation by the illuminance $E_{\perp}$ at the field perpendicular to the direction of the incident light.

3.4

slip/skid resistance (of a trafficked surface)
property of the trafficked surface which limits the relative movement between the contact patch of pedestrian footwear (slip) or a vehicle type (slip) and the surface.

3.5

pendulum test value (of a road marking)

loss of energy as the standard rubber coated slider assembly slides across the test surface and provides a standardised value of slip/skid resistance. The abbreviation PTV applies.

NOTE The above-mentioned definitions of slip/skid resistance and pendulum test value are provided in EN 13036-4. PTV is identical to the previously used SRT (Skid Resistance Tester value).

3.6

functional life (of a road marking)

period during which the road marking fulfils all the requirements of the classes initially specified by the responsible road authority.

3.7

structured road marking (in the sense of not allowing measurement of the luminance factor β and/or the PTV value)

road marking with a structured surface that does not have areas covered with road marking material of sufficient dimensions and planeness.

NOTE 1 At least some commercially available instruments allow measurement of the luminance factor β on approximately flat areas with a diameter of minimum 10 mm at the top of the structure, or a somewhat larger size deeper in the structure to allow contact of the instruments. The areas may curve with a radius of curvature of minimum 50 mm.

NOTE 2 The slider used to measure the PTV value requires approximately flat areas of a width of minimum the width of the slider (76,2 mm $\pm$ 0,5 mm) and a length of minimum the sliding length of the slider (126 mm $\pm$ 1 mm) at the top of the structure, or somewhat longer for areas deeper in the structure, in order to allow for the free swing of the glider. The areas may be crossed by gaps that take up maximum 75% of the total surface area and have widths of maximum 5 mm. The areas may have ridges or edges of blocks with a height of maximum 1,2 mm.

4 Requirements

4.1 General

The requirements specified aim primarily at the performance of road markings during their functional life. The requirements are expressed by several parameters representing different aspects of the performance of road markings and for some of these in terms of classes of increasing performance.

NOTE 1 The length of the functional life depends on whether the road marking is of short or long durability, on whether the road marking is run on by traffic (e.g. symbols on the carriageway compared to continuous edge lines), on the traffic density, on the roughness of the road surface and on matters relating to local conditions like the use of studded tyres in some countries.

NOTE 2 The classes enable different priorities to be given to the different aspects of performance of road markings depending on particular circumstances.

Classes of high performance cannot always be achieved for two or more of these parameters simultaneously. As an example, a road marking may have drop-on glass beads or drop-on anti-skid aggregates, aiming at high classes of either retroreflection (R_L) or slip/skid resistance (PTV). In general, high classes of retroreflection and slip/skid resistance cannot be obtained together

Further, the selection of performance classes implies a compromise between the needs of the drivers and the cost of supplying the performance. The needs of drivers have been studied in COST Action 331, 'Requirements for horizontal road markings'.

For skid/slip resistance, emphasis is sometimes placed on those road markings, which occupy a large percentage of the trafficked areas such as zebra crossings, arrows, transverse markings, test and symbols.

Therefore, the choice of performance classes should be fixed in national tender specifications or other national provisions after due consideration of all aspects.

4.2 Reflection in daylight or under road lighting

4.2.1 General

Reflection in daylight or under road lighting is measured

- either by the luminance coefficient under diffuse illumination Q_d as measured in accordance with annex A and as expressed in $\text{mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$.
- or by the luminance factor β measured using standard illuminant D65 defined in ISO/CIE 10526 in the $45^\circ/0^\circ$ situation meaning illumination at $(45 \pm 5)^\circ$ and measurement at $(0 \pm 10)^\circ$ where angles are measured relative to the normal to the road marking surface. Commercially available instruments use small measured areas, for instance less than 1 cm^2 . Enough readings shall be taken and averaged in order to obtain a representative measurement of the surface. The number of readings may be 3 for surfaces with little texture, but for very rough surfaces more readings are needed.

NOTE Both of the above-mentioned parameters measure the brightness of a road marking as seen in typical or average daylight or under road lighting. The main difference lies in the viewing directions, which for the luminance coefficient under diffuse illumination Q_d corresponds to a fairly long viewing distance and for the luminance factor β to viewing at close range.

For some structured road markings, the measured value of the luminance factor β is not always valid, refer to 3.7. The visibility in daylight or under road lighting for such road markings can only be judged by the luminance coefficient under diffuse illumination Q_d .

4.2.2 Luminance coefficient under diffuse illumination Q_d

The luminance coefficient under diffuse illumination Q_d shall conform to Table 1 for road markings in dry conditions.

Table 1 - Classes of Qd for dry road markings

Road marking Colour	Road surface Type	Class	Minimum luminance coefficient under diffuse illumination $Q_d \text{ mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$
White	Asphaltic	Q0	No performance determined
		Q2	$Q_d \geq 100$
		Q3	$Q_d \geq 130$
		Q4	$Q_d \geq 160$
	Cement concrete	Q0	No performance determined
		Q3	$Q_d \geq 130$
		Q4	$Q_d \geq 160$
		Q5	$Q_d \geq 200$
Yellow		Q0	No performance determined
		Q1	$Q_d \geq 80$
		Q2	$Q_d \geq 100$
		Q3	$Q_d \geq 130$
The class Q0 is for when daytime visibility is achieved through the value of the luminance factor β , see 4.2.3.			

4.2.3 Luminance factor β

The luminance factor β shall conform to Table 2 for road markings in dry conditions.

Table 2 - Classes of luminance factor β for dry road markings

Road marking colour	Road surface type	Class	Minimum luminance factor β
White	Asphaltic	B0 B2 ¹⁾ B3 ¹⁾ B4 ¹⁾ B5 ¹⁾	No performance determined $\beta \geq 0,30$ $\beta \geq 0,40$ $\beta \geq 0,50$ $\beta \geq 0,60$
	Cement concrete	B0 B3 ¹⁾ B4 ¹⁾ B5 ¹⁾	No performance determined $\beta \geq 0,40$ $\beta \geq 0,50$ $\beta \geq 0,60$
Yellow		B0 B1 ¹⁾ B2 ¹⁾ B3 ¹⁾	No performance determined $\beta \geq 0,20$ $\beta \geq 0,30$ $\beta \geq 0,40$
¹⁾ in some countries these classes cannot be maintained during a limited time period of the year during which the probability of lower performance of the road markings is high, due to the presence of water, dust, mud etc. The class B0 is for when daytime visibility is achieved through the value of the luminance coefficient under diffuse illumination Qd, see 4.2.2.			

4.3 Retroreflection under vehicle headlamp illumination

For the measurement of reflection under car headlamp illumination, the coefficient of retroreflected luminance R_L is used. It shall be measured in accordance with annex B and is expressed in $\text{mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$.

Road markings in the dry condition shall conform to Table 2; and shall conform to Table 3 during wetness and to Table 4 during rain.

NOTE The coefficient of retroreflected luminance represents the brightness of a road marking as seen by drivers of motorized vehicles under the illumination by the driver's own headlamps.

Table 3 - Classes of R_L for dry road markings

Road marking type and colour		Class	Minimum coefficient of retroreflected luminance $R_L \text{ mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$
Permanent	White	R0 R2 ¹⁾ R3 ¹⁾ R4 ¹⁾ R5 ¹⁾	No performance determined $R_L \geq 100$ $R_L \geq 150$ $R_L \geq 200$ $R_L \geq 300$
	Yellow	R0 R1 ¹⁾ R3 ¹⁾ R4 ¹⁾	No performance determined $R_L \geq 80$ $R_L \geq 150$ $R_L \geq 200$
Temporary		R0 R3 ¹⁾ R5 ¹⁾	No performance determined $R_L \geq 150$ $R_L \geq 300$
¹⁾ in some countries these classes cannot be maintained during a limited time period of the year during which the probability of lower performance of the road markings is high, due to the presence of water, dust, mud etc. The class R0 is intended for conditions, where visibility of the road marking is achieved without retroreflection under car headlamp illumination			

Table 4 - Classes of R_L for road markings during wetness

Conditions of wetness	Class	Minimum coefficient of retroreflected luminance $R_L \text{ mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$
As obtained 1 min after flooding the surface in accordance with B.5	RW0 RW1 RW2 RW3 RW4	No performance determined $R_L \geq 25$ $R_L \geq 35$ $R_L \geq 50$ $R_L \geq 75$
Class RW0 is intended for cases where this type of retroreflection is not required for economic or technological reasons		

Table 5 : Classes of R_L for road markings during rain

Conditions of rain	Class	Minimum coefficient of retroreflected luminance R_L $\text{mcd}\times\text{m}^{-2}\times\text{lx}^{-1}$
As obtained after at least 5 min exposure in accordance with B.6 during uniform rainfall of 20 mm/h	RR0	No performance determined
	RR1	$R_L \geq 25$
	RR2	$R_L \geq 35$
	RR3	$R_L \geq 50$
	RR4	$R_L \geq 75$
Class RR0 is intended for cases where this type of retroreflectivity is not required for economic or technological reasons.		

4.4 Colour

The x, y chromaticity co-ordinates for dry road markings shall be measured in the conditions that apply for the measurement of the luminance factor β , refer to 4.2, and the resulting x, y chromaticity co-ordinates shall lie within the regions defined by the corner points given in Table 6 and illustrated in Figure 1.

NOTE 1 It is customary to measure the luminance factor β and the x, y chromaticity co-ordinates in the same conditions simultaneously with a single instrument. Such instruments are well-known and commercially available from several suppliers.

NOTE 2 Intermediate measuring values are the tristimulus values X, Y and Z. The equipment can either be based on direct measurement of the tristimulus values X, Y and Z using filtered detectors or on spectral measurements followed by computation of the tristimulus values X, Y and Z. The stimulus Y is converted into β , or β is measured directly. The tristimulus values are further converted into the chromaticity co-ordinates x and y used for specification of the chromaticity of road markings by $x = X/(X+Y+Z)$ and $y = Y/(X+Y+Z)$. The principles of deriving x, y chromaticity co-ordinates are independent of the measuring conditions.

NOTE 3 Alternatively, the x, y chromaticity co-ordinates for dry road markings may be measured in the conditions that apply for the measurement of the luminance coefficient under diffuse illumination Q_d , refer to 4.2. For this case as well, the resulting x, y chromaticity co-ordinates shall lie within the regions defined by the corner points given in Table 6 and illustrated in Figure 1.

NOTE 4 The conditions that apply for the measurement of the luminance coefficient under diffuse illumination Q_d provide a more realistic picture of the colours of road markings as seen by drivers of motorized vehicles. In these conditions, un-coloured surface reflection and white aggregates in the top of the surface often make colours appear more pale, so that for instance yellow road markings have less apparent colour separation from white road markings. This has some importance, when white and yellow road markings are used for respectively permanent and temporary marking. However, the experience with the use of these conditions is limited.

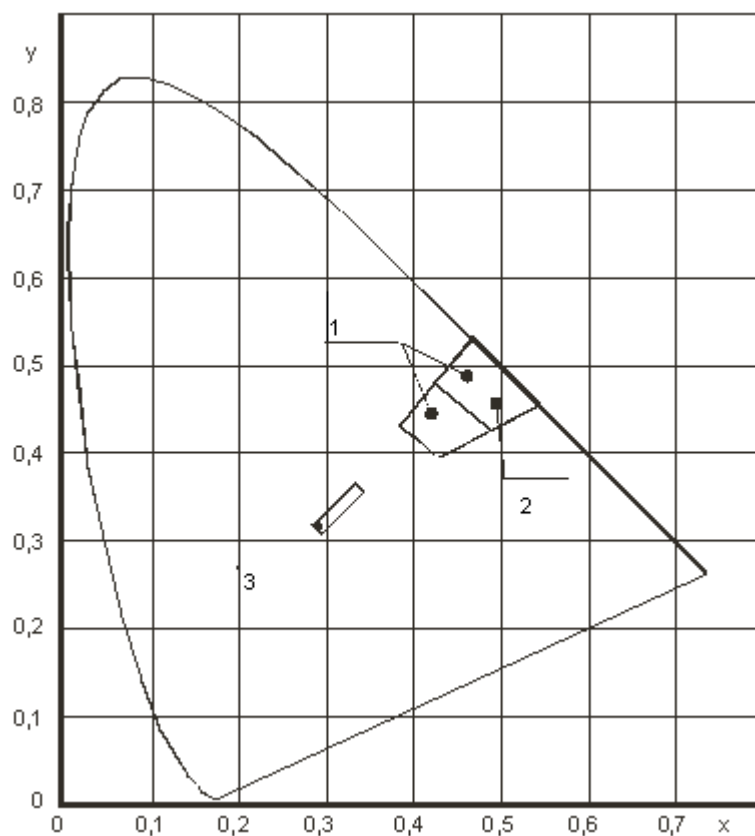
NOTE 5 The x, y chromaticity co-ordinates for dry road markings may also be measured in the conditions that apply for the measurement of the coefficient of retroreflected luminance R_L . Requirements for the resulting x, y chromaticity co-ordinates are, however, not provided.

NOTE 6 The conditions that apply for the measurement of the coefficient of retroreflected luminance R_L reflect the colours of the road markings, as seen by drivers of motorized vehicles under headlamp illumination.

Table 6 - Corner points of chromaticity regions for white and yellow road markings

Corner point No.		1	2	3	4
White road markings	x	0,355	0,305	0,285	0,335
	y	0,355	0,305	0,325	0,375
Yellow road markings class Y1	x	0,443	0,545	0,465	0,389
	y	0,399	0,455	0,535	0,431
Yellow road markings class Y2	x	0,494	0,545	0,465	0,427
	y	0,427	0,455	0,535	0,483

The classes Y1 and Y2 for yellow road markings are intended for permanent and temporary road markings respectively.

**Key**

- 1 Yellow class Y1 3 White
 2 Yellow class Y2

Figure 1 - Chromaticity regions of white and yellow road markings in the CIE chromaticity diagram

4.5 Slip/skid resistance

Unless inappropriate in view of the road marking surface, the skid/slip resistance shall be measured by means of the pendulum test value PTV according to EN 13036-4 using a wide slider and a CEN slider rubber, and shall conform to Table 7.

The pendulum test value PTV is inappropriate for some structured road markings, refer to 3.7. For those cases, other measures of slip/skid resistance normally show satisfactory values. Other measures of slid/skid resistance may be used provided that they are relevant and that the test methods show acceptable repeatability and reproducibility.

NOTE 1 The "International PIARC experiment to compare and harmonize texture and skid resistance measurements", PIARC - 01.04T - 1995, gives information about different skid resistance test methods and equipment, as well as their repeatability and correlation to PTV.

Table 7: Classes of PTV

Class	Minimum PTV value
S0	No performance determined
S1	$PTV \geq 45$
S2	$PTV \geq 50$
S3	$PTV \geq 55$
S4	$PTV \geq 60$
S5	$PTV \geq 65$
The class B0 is for when the PTV value cannot be measured.	

NOTE 2 Skid/slip resistance is a property of a road marking surface to maintain the adhesion of a vehicle type and a pedestrian footwear, it can be enhanced by adding anti-skid aggregates but with a substantial negative effect on retroreflective properties.

NOTE 3 There are numerous factors which contribute to skid resistance of road markings in use, including:

- tyre pressure, contact area, tread pattern,
- wheel alignment,
- rubber composition of the tyre or sole,
- micro- and macrotexture of the road surface in relation to the film thickness of the road marking (it is the main factor when the film thickness is less than 0,6 mm),
- frictional characteristics of the surface,
- vehicle speed,
- weather conditions, i.e. wet/dry/icy,

therefore, skid/slip resistance is not a constant but varies with climate and traffic and the effect of these on the characteristics of the surface material itself and, consequently, its evaluation incorporates a high degree of incertitude.

NOTE 4 In the case that "in situ" inspections are requested (taking into account its high degree of incertitude), other equipment more practical and safer than the pendulum presents advantages.

Annex A (normative)

Measurement method for the luminance coefficient under diffuse illumination Q_d

A.1 General requirements for measurement

A.1.1 General

Equipment for the measurement of the luminance coefficient under diffuse illumination Q_d of a field of a road marking includes an illumination system, a photometer and means to define a horizontal reference plane with a reference centre.

NOTE Diffuse illumination of a surface is obtained from a surrounding with constant luminance enclosing the hemisphere above the surface.

A.1.2 Spectral match

The photometer shall have a spectral response according to the $V(\lambda)$ distribution and the illumination shall have a spectral emission according to standard illuminant D65 as defined in ISO/CIE 10526.

NOTE 1 For the $V(\lambda)$ correction of luminance meters, see CIE publication 69.

However, it is permissible to use illuminants with other spectral distributions, if the spectral response of the photometer is modified to provide a correct overall spectral response of illumination and measurement.

NOTE 2 Only in the case of fluorescence it is necessary that the spectral emission of the light source itself is correct.

A.1.3 Arrangement of fields

The two fields of measurement and illumination shall be arranged in one of the following ways:

Method A: a part of the illuminated field is uniform and contains the measured field

Method B: a part of the measured field is uniform and contains the illuminated field

NOTE 1 Method A is based on the definition of Q_d , i.e.: $Q_d = L/E$, where L is the luminance of a measured field of a road marking and E is the illuminance on the plane of the field. The measured signal is proportional to the luminance L . The Q_d value of the field is measured by suitable calibration in proportion to the illuminance E .

NOTE 2 Method B is based on a modification of the definition of Q_d , which reads $Q_d = G \times I / \Phi$, where G is a geometrical factor, I is the reflected intensity of light from an illuminated field of a road marking and Φ is the incoming luminous flux on the field. The measured signal is proportional to the intensity I . The value of I/Φ is measured by suitable calibration in proportion to the luminous flux Φ and the Q_d value is obtained by multiplication with G .

The geometrical factor is given by $G = 1/\sin\alpha$ and has the value of $1/\sin 2,29^\circ = 25,027$ for the standard measuring condition (may be rounded off to 25).

In method A, the measured area is the area of the measured field, in method B, the measured area is the area of the illuminated field.

A.1.4 Standard measuring condition

The photometer measures a field of the reference plane located about the reference centre. The observation direction is the central direction of all rays from the measured field to the photometer leading to detection. The observation angle, symbol α , is the angle between the observation direction and the reference plane.

In the standard measuring condition, the observation angle α is $2,29^\circ \pm 0,05^\circ$ and the total angular spread of the measuring directions shall not exceed $0,33^\circ$. Diffuse illumination is obtained with a light source of constant luminance enclosing the hemisphere above the reference plane.

NOTE The standard measuring condition is intended to simulate a visual distance of 30 m for the driver of a passenger car with an eye height of 1,2 m above the road.

The measured area shall be minimum 50 cm^2 .

The equipment shall be able to cope with the character of the surfaces to be measured including surface texture, structure of structured road markings, etc., so that one of the fields remains contained within the other field. This may be achieved by sufficient reserves of the larger of the two fields or by suitable alignment procedures.

A.1.5 Other requirements

The equipment shall have sufficient sensitivity and range to accommodate Q_d values expected in use, typically 1 to the maximum of approximately $318 \text{ mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$ ($1000/\pi$). The linearity over this range of Q_d values shall be adequate for the purpose.

The equipment shall be able to cope with the conditions expected in use such as stray light entering from the surroundings.

A.2 Laboratory measurement

A.2.1 Laboratory measuring equipment and samples

Laboratory measurements are used to establish Q_d values for samples, that are to be used to test or calibrate in situ equipment.

The photometer can be a luminance meter, a spectrophotometer, or a digital camera of a good quality.

The diffuse illumination can be provided in a photometric sphere. A light source is mounted in the sphere in such a way that direct illumination falls only on the lower half of the sphere. By reflection and interreflection, the upper half of the sphere has a close approximation to a uniform luminance. The reference plane is the horizontal plane through the centre of the sphere and the reference centre is the centre of the sphere.

If samples of saturated colours are to be measured, the spectral response of the photometer shall be a good match to the $V(\lambda)$ distribution and the spectral composition of the illumination shall be a good match to standard illuminant D65. The photometer shall be mounted so as to comply with the standard measuring conditions.

In some cases, samples can be as short as 20 cm. Samples used to test or calibrate portable instruments need to be at least 40 cm long, while samples used to test or calibrate vehicle mounted equipment need to be longer. For some structured road markings, fairly long samples are required. A practical width of samples is often 20 cm.

A sample should be backed by a substrate to assist handling and should show a non-deformed surface of the road marking. The sample can either be laid directly onto the substrate, or it can be taken from a road and adhered to the substrate.

A sample is mounted in the measuring equipment and aligned so that its surface is in the reference plane, and so that the centre of the surface is in the reference centre.

A.2.2 Arrangement of fields in laboratory measurements

A sample mounted in a photometric sphere receives illumination all over its surface, and accordingly method A must be applied. The measured field must start at or after the front end of the sample at the top of the texture of the surface, and must stop at or before the back end of the sample at the bottom of the texture. The measured field must be contained within the width of the sample surface.

NOTE There is no advantage in applying method B in laboratory measurements.

A.2.3 Measurement in the laboratory

The Qd value in the unit of $\text{mcd}\times\text{m}^2\times\text{lx}^{-1}$ is obtained by $Qd = \frac{L}{E} \times 1000$

where: L = luminance reading of the road marking sample in the unit of cd/m^2

E = the illuminance on the plane of the sample in the unit of lx

A.2.4 Calibration of laboratory measurements

Direct calibration is obtained by mounting the photometer at the reference centre, with an orientation towards the upper part of the sphere, and measuring the reading m_2 . This reading multiplied by π can be used instead of the illuminance E ($E = \pi \times m_2$), followed by a calculation of the Qd value according to A.2.3.

NOTE The reading m_1 is typically a sizeable fraction of m_2 and can in principle not be larger. Accordingly, the maximum value of Qd of a surface is $1000/\pi = \text{approximately } 318 \text{ mcd}\times\text{m}^2\times\text{lx}^{-1}$.

In the direct calibration, the reading m_2 should ideally be an average of several readings at different locations at the upper part of the sphere, if the luminance of the upper part is not perfectly uniform. This may be inconvenient.

Therefore, indirect calibration by means of a sample with a known Qd value may be preferable. The 'sample' may be a curved mirror or another optical system that gives a view to the upper part of the sphere. The Qd value of the sample is $\tau \times 1000/\pi \text{ mcd}\times\text{m}^2\times\text{lx}^{-1}$, where τ is the transmittance of the optical system. However, the Qd value must be determined in a traceable manner.

Another method of indirect calibration is to measure the illuminance E by means of a separate luxmeter. This requires that both the photometer and the luxmeter are correctly calibrated to measure respectively luminance in $\text{cd}\times\text{m}^{-2}$ and illuminance in lx, or that the two are calibrated to be mutually consistent.

A.3 Portable instruments

A.3.1 Introduction

Requirements for measurement are formulated so as to be relevant for portable instruments, and so that compliance can be tested in an objective manner using the methods indicated.

NOTE The producer of an instrument may have the instrument subjected to initial type testing at a recognized laboratory in order to verify its compliance with the requirements. Optional testing may be included in order to clarify the range of application of the instrument concerning colour and structure of the road markings. The producer of an instrument may also use the methods for factory production control.

A.3.2 General

Portable instruments are intended for the measurement of Qd values of road markings on the road, but may be used to measure Qd values of road marking materials on sample panels before placing them on the road.

A portable instrument integrates the photometer and the illumination system. The reference plane and the reference centre is defined by feet of the instrument, or by other means and an alignment procedure.

Portable instruments may use collimated optics for the photometer, so that the photometer is at optical infinity, or they may use other optical principles.

Because of texture and curve of road markings on the road, particles on the surface and structure of structured road markings, a portable instrument may be tilted and shifted in height relative to the road marking surface. Portable instruments have different application ranges in this connection.

Portable instruments are used in conditions of full daylight and must be constructed so that readings are not affected by ambient light in these conditions. Some instruments may need to inform the operators by warnings or error messages if necessary.

Portable instruments are used to measure road marking surfaces of more or less gloss. Portable instruments shall be constructed so that surface reflections for Qd measurement conditions are fully included.

A.3.3 Spectral match of portable instruments

A portable instrument shall have an overall spectral response that ensures correct measurement of at least white and yellow road markings.

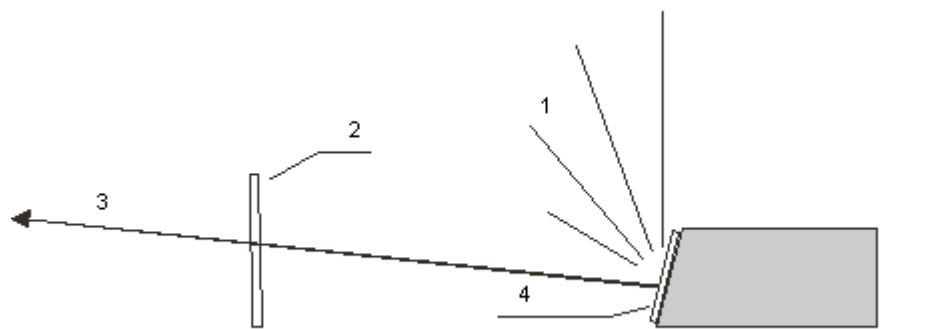
The overall response can be tested by means of a white (spectrally neutral) reflection standard, or a white road marking sample, and a set of long pass absorption filters providing colours of light yellow and dark yellow. An infrared filter can be added to the set.

The white reflection standard is mounted in the instrument and measured. An absorption filter is inserted in front of the white reflection standard so that measurement takes place through the filter. The filter must be mounted at some distance from the standard to avoid surface reflection back to the standard. Refer to Figure A.1.

The ratio of the Qd values obtained with a yellow filter inserted, and without the filter, shall be within $\pm 5\%$ of the luminous transmittance of the filter in standard illuminant D65 illumination. The Qd value with the infrared filter inserted must theoretically be naught, but a value up to $3 \text{ mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$ is acceptable.

Instead of using a white reflection standard and yellow filters, reflection standards of permanent colours white, light yellow and dark yellow may be used. After calibration of the instrument using the white calibration standard, the Qd value measured for a yellow reflection standard shall be within $\pm 5\%$ of the Qd value assigned to the standard by laboratory measurement with equipment of a good spectral match.

NOTE: Absorption long pass filters with pass wavelengths at 515 nm, 550 nm and 715 nm are commercially available and correspond to light yellow, dark yellow and infrared. Transmittance values can be derived by measurement of the individual filters.



Key

- 1 Incoming light
- 2 Absorption filter
- 3 Reflected light
- 4 White reflection standard

Figure A.1 - Position of white reflection standard and absorption filter when testing spectral response of portable Qd instruments.

A.3.4 Arrangement of fields of portable instruments

The supplier of an instrument shall declare if the instrument measures according to method A (the illuminated field contains the measured field) or B (the measured field contains the illuminated field), refer to A.1.3.

A.3.5 Standard measuring condition of portable instruments

A.3.5.1 General

The methods for determining compliance with the standard measuring condition, as supplied below, are obvious. However, other justified methods may be used.

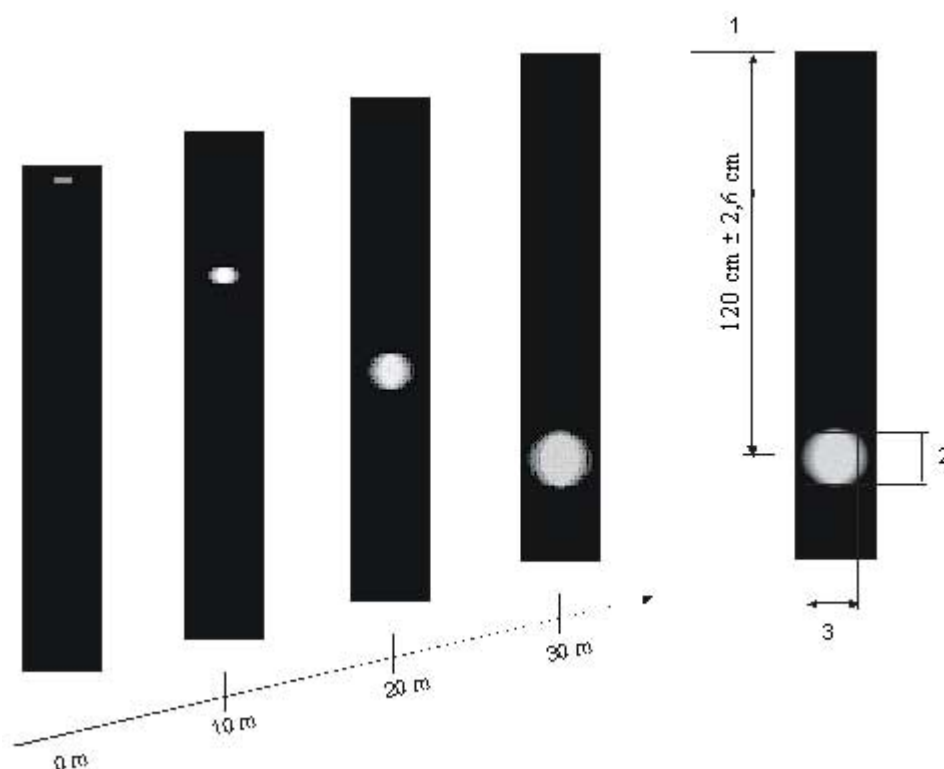
A.3.5.2 Instruments with collimated optics

For an instrument with collimated photometer optics, compliance with the standard measuring condition can be tested by putting steady light through the optical system of the photometer.

NOTE 1 Putting light through the optical systems must be done in consultation with the supplier of the instrument and according to his instructions.

When projecting the beam from the system onto a vertical plane in a darkened room, images like those of Figure A.2 are obtained. At close range, the image is formed by the exit aperture of the system, but at increasing distance the angular spread becomes dominating. The location of the beam and its dimensions are indicated in Figure A.2 for 30 m distance. The correct measure of the depth is indicated. The maximum dimensions of the beam shall be calculated and depend on the above-mentioned exit aperture.

NOTE 2 The maximum height is 17,3 cm plus the height of the exit aperture and the maximum width is 17,3 cm plus the width of the exit aperture.

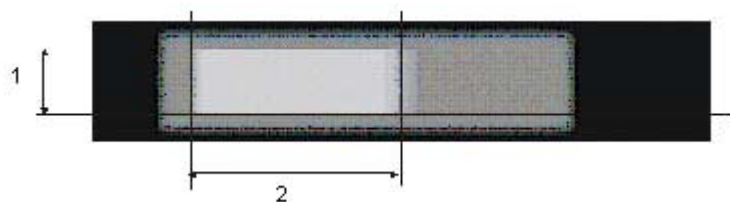


Key

- 1 plane defined by feet
- 2 height
- 3 width

Figure A.2 - The beam of collimated optics changes shape and size with distance. The location of the beam and its dimensions at 30 m distance are indicated.

With steady light through the optical system of the photometer and with the illumination system switched on, the resulting fields can be projected onto a plate as shown in Figure A.3. The plate needs in most cases to be a glass plate of a milky upper surface, so that the fields can be studied from the underside. The effectively measured area is defined by the dimensions of the smaller of the two fields.



Key

- 1 Width
- 2 length

Figure A.3 - Measured and illuminated fields projected onto a plate against the feet of the instrument. The effectively measured area is defined for the smaller of the two fields and measured from 'middle of blur' to 'middle of blur'.

Regardless of the method used by an instrument, the larger of the two fields - illuminated or measured - needs to have a reserve compared to the smaller of the fields in order that an instrument may provide reliable measurements in real conditions as mentioned in A.3.2. Alternatively, the instrument needs to have an alignment procedure.

The projection shown in Figure A.3 gives an impression of the overlay of the two fields and the reserve of the larger of the two fields. However, another test is available by shifting the height position H of the instrument relative to a road marking sample and simultaneously moving the sample horizontally so that the measured area stays in the same location on the sample surface. The movement of the sample is by $H/\sin 2,29^\circ = 25 \times H$ for method A; the sample is not to be moved for method B.

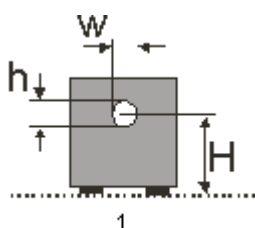
Using a non-glossy surface, the measured Q_d value shall not change by more than $\pm 10\%$, when the height position is shifted from '0 mm' to -1, 1 and 2 mm.

NOTE 3 When an instrument is able to perform at a height position H , it is able to measure structured road markings with structure heights up to that height, or with gaps between structures up to $25 \times H$.

A.3.5.3 Instruments with other optical principles

For instruments with other optical principles, possibly including alignment procedures, test methods for the compliance with the standard measuring condition have to be designed according to the construction of the instruments. A particular test shall verify that the measured Q_d value does not change by more than $\pm 10\%$, when the height position an instrument is shifted from '0 mm' to -1, 1 and 2 mm - after realignment if an alignment procedure is included with the instrument.

EXAMPLE For an instrument that simulates the full scale 30 m measuring distance in a reduced scale with a measuring distance D , the observation angle α can be determined by means of the height H of the centre of the exit pupil of the observation optics by $\alpha = \tan^{-1}(H/D)$. The angular spread of the observation directions is determined in the same manner using the height h and the width w of the exit pupil of the observation optics. Refer to the Figure below.



Key

- 1 reference plane

A.3.6 Illumination system for portable instruments

The illumination system shall provide diffuse illumination, which is obtained by indirect illumination through an opening of a photometric sphere, or other device, with an interior of white, matt finish.

When using a photometric sphere with the opening at the bottom, the direct illumination shall cover all of the interior sphere surface above the opening with such a degree of uniformity that the ratio of the smallest to the largest luminance of the interior sphere surface is minimum 0,8, when measured in directions through the centre of the opening with a circular measuring field of a diameter of 0,1 times the diameter of the sphere.

When the height of the remaining part of the sphere, after introducing the opening, is minimum 0,8 times the diameter of the sphere, no further measures to secure uniformity of luminance are required.

When less of the sphere surface remains than stated above, or when the sphere is approximated by other shapes, enough testing shall be carried out to verify that interior surfaces have approximately constant luminance. The ratio of the smallest to the largest luminance of interior surfaces shall be minimum 0,8, when measured in different directions through different locations at the opening. The test shall be carried out with the opening empty, and shall be repeated with the opening covered by a reflecting surface of white, matt finish with suitable holes to allow for the measurements.

NOTE Reflection from a surface in the opening may disturb the uniformity of luminance of the interior surfaces of the illumination system.

When the illumination system is based on a sphere and the height of the remaining part of the sphere, after introducing the opening, is minimum 0,8 times the diameter of the sphere, the uniformity of luminance is not disturbed to a degree that affects the measurements significantly.

When less of the sphere surface remains, or when the sphere is approximated by other shapes, there is no other general way to secure uniformity of luminance than to test the uniformity directly, both with the opening empty, and with the opening covered by a reflecting surface.

When an instrument is placed on a road marking, the opening of the illumination system shall be close to the road marking surface, as surface reflections in glossy surfaces will not otherwise be included in the measured Q_d value.

A.3.7 Other requirements for portable instruments and options

The sensitivity, range and linearity of portable instruments may be tested by means of suitable samples. Requirements are provided in A.1.5.

NOTE Interreflection between a surface in the opening and interior surfaces of the illumination system may cause an increase of the illuminance of the sample surface, which depends in a non-linear way on the reflectance of the sample surface. This cause of non-linearity must be eliminated as well as other causes of non-linearity, for instance by monitoring the illuminance of the sample surface.

Offset by stray light in daylight conditions may be tested by measurement in full daylight, where readings obtained without additional cover of an instruments are compared to readings obtained with additional cover by a black cloth or other obstructions about the instrument. The worst case is mostly the one, where the instrument faces a low sun, in particular when placed on a specular surface. A powerful projector lamp, or a mirror used to reflect the sun, may also be used for the testing. Due to variability of daylight and road marking surface conditions, a precise test cannot be defined, but offsets should in general not exceed $5 \text{ mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$ for common conditions.

Sensitivity to surface reflections may be tested by measurement of samples with strong surface reflection (as for example a smooth substrate with a glossy paint) and known Qd values. A measured Qd value shall be at least 90 % of the known value.

NOTE High ability of instruments to be able to cope with surface reflections can be checked by using the following samples. A black, acrylic plate with a smooth, clean surface shows virtually pure surface reflection and is therefore suitable for testing the sensitivity to surface reflections. The Qd value is approximately $253 \text{ mcd}\times\text{m}^{-2}\times\text{lx}^{-1}$, but this should be verified by measurement or theoretical consideration (Fresnel equations for surface reflection). A white, acrylic plate with a smooth, clean surface mounted on a white substrate of high reflectance shows a high degree of surface reflection and has a Qd value close to the theoretical maximum of approximately $318 \text{ mcd}\times\text{m}^{-2}\times\text{lx}^{-1}$, typically approximately $312 \text{ mcd}\times\text{m}^{-2}\times\text{lx}^{-1}$, which makes the determination of the Qd value reliable.

Filters or reflection standards of other colours than described in A.3.3 may be added to the test the ability of an instrument to measure road markings of such colours.

Other height positions than mentioned in A.3.4 (-1, 0, 1 mm and 2 mm) may be included to demonstrate the ability of an instrument to measure road markings with extreme texture, in particular structured road markings.

A.3.8 Calibration of portable instruments

A portable instrument shall be calibrated by means of a traceable standard sample with a known Qd value. Independent calibration of the standard sample must be possible. For instruments working according to method A, an optical system that gives a view to the illumination system is particularly suitable, refer to A.2.4. A transfer standard may be used for routine tests of the calibration in order to avoid frequent handling of the standard in road conditions.

A.3.9 Measurement using portable instruments

Portable instruments are to be calibrated, maintained and used according to instructions by the instrument supplier.

Quality control of road markings is to be carried out according to a plan, which describes sampling and minimum measured area per each individual Qd value to be entered into a report. It is often necessary to average two or more readings of Qd at slightly different positions in order to reach the minimum measured area, depending on the effective measured area provided by the instrument.

For a structured road marking, it is necessary to establish if the portable instrument in question is able to measure the structured road marking with the actual height of structures and gap between these, refer to A.3.5. The Qd value is established as the average of a number of readings taken with shifts of the instrument in steps along the marking, in total covering one or more spacing of structures.

A.4 Vehicle mounted equipment

Vehicle mounted equipment may be used to measure Qd values of road markings while moving at traffic speed, and can be used for longer stretches of road than portable instruments and in cases where the use of portable instruments requires extensive precautions, in particular on motorways.

NOTE: At present, vehicle mounted equipment uses daylight illumination, which under an overcast sky with a reasonable free view to the horizon, approximates diffuse illumination. Due to variations in daylight, luminance and illuminance should be measured simultaneously. Suitable daylight illumination does not occur very often.

Annex B (normative)

Measurement method for the coefficient of retroreflected luminance R_L

B.1 General requirements for measurement

B.1.1 Introduction

Equipment for the measurement of the coefficient of retroreflected luminance R_L of a field of a road marking includes an illumination system, a photometer and means to define a horizontal reference plane with a reference centre.

B.1.2 Spectral match

The photometer shall have a spectral response according to the $V(\lambda)$ distribution and the illumination shall have a spectral emission according to standard illuminant A as defined in ISO/CIE 10526.

NOTE For the $V(\lambda)$ correction of luminance meters, see CIE publication 69.

However, it is permissible to use illuminants with other spectral distributions, if the spectral response of the photometer is modified to provide a correct overall spectral response of illumination and measurement.

NOTE Only in the case of fluorescence is it necessary that the spectral emission of the light source itself is correct, but it is unlikely that fluorescence will occur to a significant degree in conditions of R_L measurement.

B.1.3 Arrangement of fields

The two fields of measurement and illumination shall be arranged in one of the following ways:

Method A: a part of the illuminated field is uniform and contains the measured field

Method B: a part of the measured field is uniform and contains the illuminated field

NOTE 1 Method A is based on the definition of R_L , i.e.: $R_L = L/E_{\perp}$, where L is the luminance of a measured field of a road marking and $E_{\perp}$ is the illuminance at the field on a plane perpendicular to the direction of illumination. The measured signal is proportional to the luminance L . The R_L value of the field is measured by suitable calibration in proportion to the illuminance $E_{\perp}$.

NOTE 2 Method B is based on a modification of the definition of R_L , which reads $R_L = G \times I / \Phi$, where G is a geometrical factor, I is the reflected intensity of light from an illuminated field of a road marking and Φ is the incoming luminous flux on the field. The measured signal is proportional to the intensity I . The value of I/Φ is measured by suitable calibration in proportion to the luminous flux Φ and the R_L value is obtained by multiplication with the value of G that applies for the standard measuring condition.

The geometrical factor is given by $G = \sin \epsilon / \sin \alpha$ and has the value of $G = \sin 1,24^\circ / \sin 2,29^\circ = 0,54159$ for the standard measuring condition (may be rounded off to 0,542).

In method A, the measured area is the area of the measured field, in method B, the measured area is the area of the illuminated field. The measured area may be further limited by the width of the road marking surface, refer to B.2.2.

B.1.4 Standard measuring condition

The photometer measures a field of the reference plane, which is located about the reference centre. The observation direction is the central direction of all rays from the measured field to the photometer leading to detection. The observation angle, symbol α , is the angle between the observation direction and the reference plane.

The illumination system illuminates a field of the reference plane, also located about the reference centre. The illumination direction is the central direction of all rays from the illumination system to the illuminated field. The illumination angle, symbol ε , is the angle between the illumination direction and the reference plane.

In the standard measuring condition, the observation angle α is $2,29^\circ \pm 0,05^\circ$, the illumination angle ε is $1,24^\circ \pm 0,05^\circ$ and the angle between the two vertical planes containing respectively the observation and the illumination directions is $0^\circ \pm 0,05^\circ$.

NOTE The standard measuring condition is intended to simulate a visual distance of 30 m for the driver of a passenger car with an eye height of 1,2 m and a headlamp mounting height of 0,65 m above the road.

The total angular spread of the measuring directions shall not exceed $0,33^\circ$. The total angular spread of the illumination directions shall not exceed $0,33^\circ$ in the plane parallel to the reference plane and $0,17^\circ$ in the plane perpendicular to the reference plane.

The measured area shall be minimum 50 cm^2 .

The equipment shall be able to cope with the character of the surfaces to be measured including surface texture, structure of structured road markings, etc., so that one of the fields remains contained within the other field. This may be achieved by sufficient reserves of the larger of the two fields or by suitable alignment procedures.

B.1.5 Other requirements

The equipment shall have sufficient sensitivity and range to accommodate R_L values expected in use, typically 1 to $2000 \text{ mcd} \cdot \text{m}^{-2} \cdot \text{lx}^{-1}$. The linearity over the range of R_L values expected in use shall be adequate for the purpose.

The equipment shall be able to cope with the conditions expected in use such as stray light entering from the surroundings or caused by surface reflections.

B.2 Laboratory measurement

B.2.1 Laboratory measuring equipment and samples

Laboratory measurements are used to establish R_L values for samples, that are to be used to test or calibrate in situ equipment.

The photometer can be a luminance meter, a spectrophotometer, or a digital camera of a good quality. The illumination system can use a halogen incandescent lamp with a reflector or other suitable optics. The reference plane and the reference centre is defined by means of a sample holder and an alignment procedure.

If samples of saturated colours are to be measured, the spectral response of the photometer shall be a good match to the $V(\lambda)$ distribution and the spectral composition of the illumination shall be a good match to standard illuminant A. The photometer and the illumination system shall be mounted so as to comply with the standard measuring condition.

In some cases, samples can be as short as 20 cm. Samples used to test or calibrate portable instruments need to be at least 40 cm long, while samples used to test or calibrate vehicle mounted equipment need to be longer. For some structured road markings, fairly long samples are required. A practical width of samples is often 20 cm.

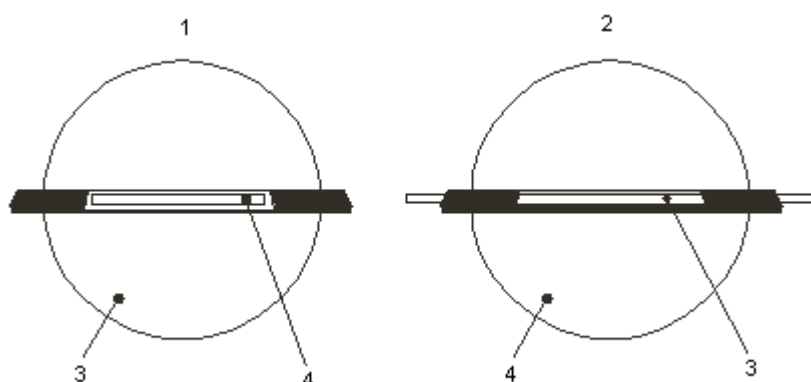
A sample should be backed by a substrate to assist handling and should show a non-deformed surface of the road marking. The sample can either be laid directly onto the substrate, or it can be taken from a road and adhered to the substrate.

A sample is mounted in the measuring equipment and aligned so that its surface is in the reference plane, and so that the centre of the surface in the reference centre.

B.2.2 Arrangement of fields in laboratory measurements

Method A can be applied by illuminating all of the sample surface, and measuring a field of the surface that starts at or after the front end of the sample at the top of the texture of the surface, and stops at or before the back end of the sample at the bottom of the texture. The field can be wider than the surface provided that the backing plate and any other items in the field are suitably non-reflecting or covered with black cloth. A digital camera, in which the measured field may be set according to the sample surface, is particularly suitable.

Method B can be applied by measuring all of the surface, and illuminating only a band across the surface that starts at or after the front end of the sample at the top of the texture of the surface, and stops at or before the back end of the sample at the bottom of the texture. This requires an illumination system with optics as in a slide projector, and a slit aperture to create the band of light.



Key

1	Method A (reduced field of measurement)	3	Illuminated field
2	Method B (band of light)	4	Measured field

Figure B1 - Methods A and B

B.2.3 Measurement in the laboratory

The R_L value in the unit of $\text{mcd} \times \text{m}^2 \times \text{lx}^{-1}$ is obtained by
$$R_L = \frac{(m_1 - m_0)d^2}{\Phi} \times G \times 1000$$

where:

m_0 = background reading

m_1 = reading of the road marking sample

d = distance from the reference centre to the photometer (m)

G = geometrical factor with the value of 0,542

Φ = the luminous flux falling on the measured surface

The background reading m_0 is obtained with the road marking sample replaced by a black non-reflecting surface, for instance a smooth black plastic plate.

The luminous flux falling on the measured surface Φ is to be determined during calibration in a scale compatible with the scale of the readings m_0 and m_1 , refer to B.2.4.

B.2.4 Calibration of laboratory measurements

Direct calibration is obtained by mounting the photometer at the reference centre, with an orientation towards the illumination system, and measuring the reading m_2 .

The reading m_2 must be obtained with illumination of the full sensitive area of the photometer. For method A, the illumination will normally cover the full sensitive area; while for method B, the height of the band of light must often be increased to provide illumination of the full sensitive area, or a correction must be introduced. The reading m_2 is several decades larger than typical readings m_1 , and accordingly the linearity of the photometer must be verified over the full range.

The reading m_2 is used to derive the luminous flux falling on the measured surface Φ by $\Phi = m_2 \times A_{\perp}$, where $A_{\perp}$ is the area of the measured surface projected onto a plane perpendicular to the illumination direction. For method A, $A_{\perp}$ is determined as $A \times \sin \epsilon$, where A is the surface area of the sample and ϵ is the illumination angle equal to $1,24^\circ$ for the standard measuring condition. For method B, $A_{\perp}$ is determined as the height of the illumination band times the width of the sample.

NOTE 1 The direct calibration, and other calibration methods, is described in CIE publication 54.2.

NOTE 2 For method A, the correct value of Φ depends on the actual value of ϵ . This shows that the sample must be aligned correctly, or the R_L value will be offset. An offset occurs also, if the observation angle α is not set correct, so that the total offset is in proportion of 0,542 to the actual value of $\sin \epsilon / \sin \alpha$. Such an offset does not occur for method B.

Indirect calibration by means of a sample with a known R_L value is often preferable. A sample in the form of a tilted white ceramic surface is particularly suitable. A constant C is determined so that $R_L = C \times (m_1 - m_0)$ is correct for the standard and then used for other samples. For method B, the constant C must be modified in proportion to the ratio of the widths of the standard and the samples. The same applies for method A, when the measured area is wider than the sample.

The R_L value of the standard must be measured with direct calibration or with another traceable calibration technique.

NOTE 3 A standard with a tilted surface to be used for method B must be assigned the value of 0,542 times the measured R_L value.

B.3 Portable instruments

B.3.1 Introduction

Requirements for measurement are formulated so as to be relevant for portable instruments, and so that compliance can be tested in an objective manner using the methods indicated.

NOTE The producer of an instrument may have the instrument subjected to initial type testing at a recognized laboratory in order to verify its compliance with the requirements. Optional testing may be included in order to clarify the range of application of the instrument concerning colour and structure of the road markings. The producer of an instrument may also use the methods for factory production control.

B.3.2 General

Portable instruments are intended for the measurement of R_L values of road markings on the road, but may be used to measure R_L values of road marking materials on sample panels before placing them on the road.

A portable instrument integrates the photometer and the illumination system. The reference plane and the reference centre is defined by feet of the instrument, or by other means and an alignment procedure.

Portable instruments may use collimated optics, so that the photometer and the illumination system are at optical infinity, or they may use other optical principles.

Because of texture and curve of road markings on the road, particles on the surface and structure of structured road markings, a portable instrument may be tilted and shifted in height relative to the road marking surface. Portable instruments have different application ranges in this connection.

Portable instruments are used in conditions of full daylight and must be constructed so that readings are not affected by ambient light in these conditions. Some instruments may need to inform the operators by warnings or error messages if necessary.

Portable instruments are used to measure wet road marking surfaces, whose R_L values might be small, while surface reflections are strong. Portable instruments shall be constructed, or compensated, so that surface reflections are not provoking offset of the readings.

B.3.3 Spectral match of portable instruments

A portable instrument shall have an overall spectral response in the visual range, refer to B.1.2, that ensures correct measurement of at least white and yellow road markings.

The overall response can be tested by means of a white (spectrally neutral) reflection standard, or a white road marking sample, and a set of long pass absorption filters providing colours of light yellow and dark yellow. An infrared filter can be added to the set.

The white reflection standard is measured. An absorption filter is inserted in front of the white reflection standard, so that illumination and measurement takes place through the filter, and a new measurement is made. The filter must be mounted with a small tilt to avoid signal by surface reflection, and at some distance from the standard to avoid surface reflection back to the standard. Refer to Figure B.2.

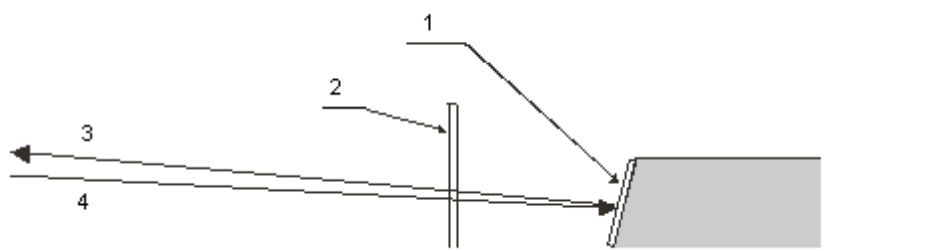
The ratio of the R_L values obtained with a yellow filter inserted, and without the filter, shall be within $\pm 5\%$ of the luminous transmittance of an air space pair of two such filters in standard illuminant A illumination. The R_L value with an infrared filter inserted must theoretically be naught, but a value up to $3 \text{ mcd} \times \text{m}^{-2} \times \text{lx}^{-1}$ is acceptable.

For some instruments, it may be more practical to insert filters to cover either illumination or measurement, not both. In that case, the ratio of the readings obtained with a yellow filter inserted, and without the filter, shall be within $\pm 5\%$ of the luminous transmittance of a single such filter in standard illuminant A illumination.

Instead of using a white reflection standard and yellow filters, reflection standards of permanent colours white, light yellow and dark yellow may be used. After calibration of the instrument using the white calibration standard, the R_L

value measured for a yellow reflection standard shall be within $\pm 5\%$ of the R_L value assigned to the standard by laboratory measurement with equipment of a good spectral match.

NOTE Absorption long pass filters with pass wavelengths at 515 nm, 550 nm and 715 nm are commercially available and correspond to light yellow, dark yellow and infrared. Transmittance values for air space pairs of filters can be based on measurement of the individual filters.



Key

- 1 White reflection standard
- 2 Absorption filter
- 3 Reflected light
- 4 Incoming light

Figure B.2 - White reflection standard and absorption filter for testing overall spectral response of portable instruments.

B.3.4 Arrangement of fields of portable instruments

The supplier of an instrument shall declare if the instrument measures according to method A (the illuminated field contains the measured field) or B (the measured field contains the illuminated field), refer to B.1.3.

Measurement of a white tilted standard provides direct verification of the method used by an instrument. An instrument using method A will provide an R_L value, which is the same or close to the actual R_L value of the standard, while an instrument using method B will provide an R_L value, which is 0,542 times lower.

NOTE The actual R_L value of the white tilted standard may be obtained by laboratory measurement, or the value may be estimated, as a good accuracy is not needed for the distinction between instruments using methods A and B. A white surface has mostly a reflectance of approximately 0,9, and when used for a tilted standard, the R_L value becomes approximately $286 \text{ mcd}\cdot\text{m}^{-2}\cdot\text{lx}^{-1}$.

B.3.5 Standard measuring condition of portable instruments

B.3.5.1 General

The methods for determining compliance with the standard measuring condition, as supplied below, are obvious. However, other justified methods may be used.

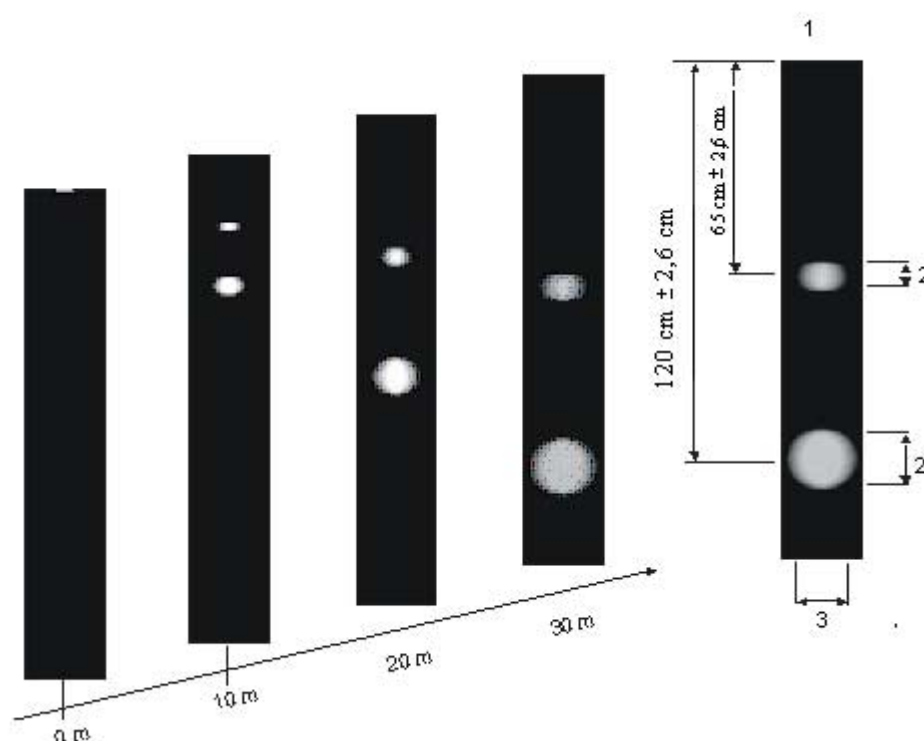
B.3.5.2 Instruments with collimated optics

For an instrument with collimated optics, compliance with the standard measuring condition can be tested by putting steady light through the optical system of the photometer and the illumination system.

NOTE 1 Putting light through the optical systems should be done in consultation with the supplier of the instrument and according to his instructions.

When projecting the beams from both systems onto a vertical plane in a darkened room, images like those of Figure B.3 are obtained. At close range, the images are formed by the exit apertures of the systems, but at increasing distance the angular spreads become dominating. The locations of the beams and their dimensions are indicated in Figure B.3 for 30 m distance. The correct measure of the depth is indicated. The maximum dimensions of the beams shall be calculated and depend on the above-mentioned exit apertures.

NOTE 2 For the observation beam, the maximum height is 17,3 cm plus the height of the exit aperture and the maximum width is 17,3 cm plus the width of the exit aperture. For the illumination beam, the maximum height is 8,6 cm plus the height of the exit aperture and the maximum width is 17,3 cm plus the width of the exit aperture.



Key

- 1 Plane defined by feet
- 2 height
- 3 width

Figure B.3 - The beams of collimated optics change shape and size with distance. The locations of the beams and their dimensions at 30 m distance are indicated.

With steady light through the optical systems of the photometer and the illumination system, the resulting beams can be projected onto a plate as shown in Figure B.4. The plate needs in most cases to be a glass plate of a milky upper surface, so that the fields can be studied from the underside. The effectively measured area is defined by the dimensions of the smaller of the two fields.



Key

- 1 width
- 2 length

Figure B.4 - Measured and illuminated fields projected onto a plate against the feet of the instrument. The effectively measured area is defined for the smaller of the two fields and measured from 'middle of blur' to 'middle of blur'.

Regardless of the method used by an instrument, the larger of the two fields - illuminated or measured - needs to have a reserve compared to the smaller of the fields in order that an instrument may provide reliable measurements in real conditions as mentioned in B.3.2.

The projection shown in Figure B.4 gives an impression of the overlay of the two fields and the reserve of the larger of the two fields. However, another test is available by shifting the height position H of the instrument parallel to a road marking sample and simultaneously moving the sample horizontally so that the measured area stays in the same location on the sample surface. The movement of the sample is by $H/\sin 2,29^\circ = 25 \times H$ for method A and by $H/\sin 1,24^\circ = 46 \times H$ for method B.

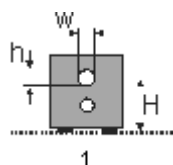
The measured R_L value shall not change by more than $\pm 10\%$, when the height position is shifted from '0 mm' to -1, 1 and 2 mm.

NOTE 3 When an instrument is able to perform at a height position H , it is able to measure structured road markings with structure heights up to that height, or with gaps between structures up to the corresponding shift (either $25 \times H$ for method A or $46 \times H$ for method B).

B.3.5.3 Instruments with other optical principles

For instruments with other optical principles, possibly including alignment procedures, test methods for the compliance with the standard measuring condition have to be designed according to the construction of the instruments. A particular test shall verify that the measured R_L value does not change by more than $\pm 10\%$, when the height position of an instrument is shifted from '0 mm' to -1, 1 and 2 mm - after realignment if an alignment procedure is included with the instrument.

EXAMPLE: For an instrument that simulates the full scale 30 m measuring distance in a reduced scale with a measuring distance D , the observation angle α can be determined by means of the height H of the centre of the exit pupil of the observation optics by $\alpha = \tan^{-1}(H/D)$. The angular spread of the observation directions is determined in the same manner using the height h and the width w of the exit pupil of the observation optics. Refer to the Figure below.



- Key**
- 1 reference plane

The illumination angle ε and the angular spread of illumination can be determined in the same manner.

B.3.6 Other requirements for portable instruments and options

The sensitivity, range and linearity of portable instruments may be tested by means of suitable samples. Requirements are provided in B.1.5.

Offset by stray light in daylight conditions may be tested by measurement in full daylight, where readings obtained without additional cover of an instruments are compared to readings obtained with additional cover by a black cloth or other obstructions about the instrument. The worst case is the one, where the instrument faces a low sun, in particular when placed on a specular surface. A powerful projector lamp, or a mirror used to reflect the sun, may also be used for the testing. Due to variability of daylight and road marking surface conditions, a precise test cannot be defined, but offsets should in general not exceed $5 \text{ mcd}\cdot\text{m}^{-2}\cdot\text{lx}^{-1}$ for common conditions.

Sensitivity to surface reflections may be tested by measurement of a black acrylic plate with a smooth, clean surface, whose R_L value is naught. The measured R_L value shall be maximum $5 \text{ mcd}\cdot\text{m}^{-2}\cdot\text{lx}^{-1}$.

Filters or reflection standards of other colours than described in B.3.3 may be added to the test the ability of an instrument to measure road markings of such colours.

Other height positions than mentioned in B.3.4 (-1, 0, 1 and 2 mm) may be included to demonstrate the ability of an instrument to measure road markings with extreme texture, in particular structured road markings.

B.3.7 Calibration of portable instruments

A portable instrument shall be calibrated by means of a traceable standard sample with a known R_L value. Independent calibration of the standard sample must be possible. A tilted white surface is particularly suitable, refer to B.2.4. A transfer standard may be used for routine tests of the calibration in order to avoid frequent handling of the standard in road conditions.

B.3.8 Measurement using portable instruments

Portable instruments are to be calibrated, maintained and used according to instructions by the instrument supplier.

Quality control of road markings is to be carried out according to a plan, which describes sampling and minimum measured area per each individual R_L value to be entered into a report. It is often necessary to average two or more readings of R_L at slightly different positions in order to reach the minimum measured area, depending on the effective measured area provided by the instrument.

For a structured road marking, it is necessary to establish if the portable instrument in question is able to measure the structured road marking with the actual height of structures and gap between these, refer to B.3.5. The R_L value is established as the average of a number of readings taken with shifts of the instrument in steps along the marking, in total covering one or more spacings of structures.

B.4 Vehicle mounted equipment

Vehicle mounted equipment is used to measure R_L values of road markings while moving at traffic speed, and can be used for longer stretches of road than portable instruments and in cases where the use of portable instruments requires extensive precautions, in particular on motorways.

When operated in a stationary mode, vehicle mounted equipment should in principle comply with the same requirements as for portable instruments, refer to B.3.

Vehicle mounted equipment has the advantage to portable equipment that it can be operated while driving at speed. This, on the other hand, causes some additional difficulties of the measurement, which may lead to compromises with B.3, or cause additional variation of measured values.

When used at traffic speed, vehicle mounted equipment should be able to cope with the movements of the vehicle and with changing conditions of daylight.

NOTE Vehicle mounted equipment cannot be brought into contact with the road marking surface, alignment is disturbed by movement of the vehicle and curve of the road, lighting conditions change by passage in and out of shadows, broken lines give variable signal, etc.

Vehicle mounted equipment shall be calibrated by means of standard sample with a known R_L value measured in laboratory conditions in a traceable manner. A tilted white surface is particularly suitable, refer to B.2.4. A transfer standard may be used for routine tests of the calibration in order to avoid frequent handling of the standard in road conditions.

B.5 Condition of wetness

The test condition shall be created using clean water poured from a bucket from a height of about 0,3 m above the surface. The water is poured evenly along the test surface so that a crest of water momentarily floods the measuring field and its surrounding area. The coefficient of retroreflected luminance R_L in condition of wetness shall be measured under the test condition (60 ± 5) seconds after the water has been poured. The amount of water to be poured at one location is at least 3 litres.

The test condition can also be created (60 ± 5) seconds after stopping artificial rain as described in B.6.

NOTE 1 The test condition is not applicable for newly applied road markings, when the surface is hydrophobic so that water forms puddles on the surface. The hydrophobic surface property normally disappear a few weeks after a road marking is applied.

NOTE 2 In hot, sunny weather the road surface may be so hot that the road surface dries out very quickly. It helps to pour water on the road surface more than once to cool it down.

If portable equipment is cool after transport, dew will form on its optics when placing it on a hot, wet road surface. The portable equipment should be allowed to warm up and the road surface should be cooled down.

B.6 Condition of rain

Test conditions shall be created using clean water giving artificial rainfall, without mist or fog, at an average intensity of (20 ± 2) mm/h over an area that is at least twice the width of the sample under test and of a minimum width of 0,3 m, and which is more than 25% longer than the measuring field. The variation in rainfall between the lowest and the greatest intensity shall be no greater than the ratio 1 to 1,7.

Measurements of the coefficient of retroreflected luminance R_L in condition of rain shall be made after 5 min of continuous rain, or when stability of measurement is achieved, and while rain is falling.

The intensity of the rain can be determined by measuring the volume of water collected in six flat trays within a specified period. A longitudinal row of trays can be used for the minimum width of the field of 0,3 m.

NOTE 1 The test condition is not applicable for newly applied road markings, when the surface is hydrophobic so that water forms puddles on the surface. The hydrophobic surface property normally disappear a few weeks after a road marking is applied.

NOTE 2 Protection against wind is often required, such protection should be open at the back in order to avoid reflections. Any mist or fog should be let out before measurement.

NOTE 3 Measurements can be made at night using a luminance meter of suitable specifications and a powerful lamp. Measurements can also be made with portable instruments or vehicle based equipment provided that the measured field lies in front of the instrument or equipment.

NOTE 4 Measurements can also be made in the laboratory on 2 m long samples supported by rigid plates. For a realistic drainage, samples should be tilted 2% sideways and the supporting plate should have an additional width of $(10 \pm 0,5)$ cm on the side tilted upwards.

Bibliography

CIE 69: 1987	Methods of characterising the performance of radiometers and photometers : Performance characteristics and specifications.
COST Action 331: 1999	Requirements for horizontal road marking, European Commission
ASTM D4061 - 94	Standard test method for retroreflectance of horizontal coatings
PIARC - 01.04T - 1995	International PIARC experiment to compare and harmonize texture and skid resistance measurements

Translation of

Test Certificate of the suitability of the dynamic retroreflectometer ZDR 6020 for the dynamic measurement of the coefficient of retroreflected luminance R_L of road markings

(This test certificate consists of 10 pages and an attachment of 2 pages)

1 Employer

The order for the preparation of the report was given by Zehntner GmbH Testing Instruments, Gewerbestrasse 4, CH-4450 Sissach/Switzerland.

2 Order subject

Determination of the suitability of the Zehntner-Dynamic Retroreflectometer ZDR 6020 (hereafter "ZDR 6020") for the dynamic measurement of the coefficient of retroreflected luminance R_L of road markings by method of 2 different comparative measurements.

2.1 Comparison of the measurements with a static measuring device

Assessment of the precision of the ZDR 6020 by comparing the R_L measurements of the ZDR 6020 with a portable, static retroreflectometer ZRM 6013 on a road marking test field.

2.2 Comparison of the measurements at different measuring speeds

Assessment of the dependence of the measured R_L values obtained by the ZDR 6020 on the measuring speed on a road under traffic.

3 Tested measuring system

The description of the measuring systems follows the data specified by the employer and inspection of the tester. The retroreflectometer ZDR 6020 is installed on a vehicle and enables the measurement of the coefficient of retroreflected luminance R_L on roads under traffic at travelling speeds up to 120 km/h. Measurements can be carried out during the day or at night.

3.1 General mode of operation

The ZDR 6020 consists mainly of a measuring head, a connection box and a laptop with separate touch panel. For the measuring process, the measuring head is installed on the outside of the vehicle and connected to the vehicle. The position of the marking is visible for the vehicle driver on the touch panel. The driver navigates the vehicle in such

a way that the measuring area is always over the marking. The measuring area hits the marking 6 m in front of the measuring head. The operator has the possibility to store the measured data directly into a measuring file. As a general rule, an average value is calculated and saved for section of 50 or 100 m.

The measuring head is responsible for the logging of the measuring data. The data are processed within the measuring head by an integrated computer and transferred directly to the laptop via Ethernet. During the measuring process the measuring head is connected to a connection box installed in the vehicle. The connection box is responsible for providing supply voltage for the measuring head and acts as the central interface for all cables and connections.

The Laptop is mounted on a console on the front passenger side of the vehicle and is used for operation of the measuring software and for storing the measurement data. The touch panel displays the current measuring value and a representative image of the retroreflection data of the marking.

Additionally to the retroreflection value, data like temperature, humidity, driven speed, GPS- coordinates, pictures and voice files are logged.

3.2 Technical specifications of the measuring head

Measuring geometry	30 m Geometry
Illumination angle ϵ	1,24°
Observation angle α	2,29°
Length of measuring area	1 m
Width of measuring area	0,5 m
Number of sensors	16
Measuring position	6 m in front of the measuring head (exit/entrance lense)
Illumination aperture	0,17° x 0,33°
Observation aperture	0,33° x 0,33°
Light source	Halogen lamp 100 W, stabilised voltage supply
Modulation frequency	600 Hz
Sensor	Silicium photodiode

The measuring geometry (illumination angle, observation angle, apertures) corresponds to the EN 1436, valid edition of January 2009 (German edition), observation angle $\alpha = 1,24^\circ$ and illumination angle $\epsilon = 2,29^\circ$.

3.3 Measuring principle

The measuring head contains a light emitting unit, sending a light beam onto the marking, and a light receiving unit which translates the light reflected by the marking in measurable signals. These signals are pre-amplified, filtered and then digitalized by a A/D converter. The CPU picks up these data from the A/D converter, processes them and sends them to the laptop in the vehicle.

The light emitting unit consists of a halogen lamp, a chopper (perforated disk) rotating with constant speed and a lens-based optical system. The chopper modulates the light with 600 Hz before it hits the marking 6 m in front of the measuring head.

The receiving unit consists of 16 photodiodes monitoring the illuminated measuring field on the marking through a lens-based optical system. The measuring principle follows the lock-in principle with phase sensitive detection. A sensor identifies the position of the chopper (chopper is sending light or not). If the chopper is open, the data from the 16 sensors are digitalized by the A/D converter and buffered in the CPU. These data are called signal. The next step is to wait until the chopper is closed, and to take readings of the 16 sensors again. These are the offset-data. Both data packages are subtracted in the CPU, thus resulting in the actual measuring value.

Signal processing: the signal of the sensor is amplified by a pre-amplifier and reaches a high-pass filter with a threshold frequency of 0.48 Hz. Then, the signal passes through a second amplification level containing a low-pass filter with a threshold frequency of 160 Hz. Afterwards the signal reaches the A/D converter. The value of the surrounding light is measured simultaneously by A/D conversion of the raw signal when the chopper is closed.

4 Data processing and evaluation of the measuring data

The evaluation and processing of the measuring data is executed by the software "Retrograbber" which is running on the laptop during the measuring process. The software receives digital measuring values as raw data from the measuring head. These data are then averaged over the previously chosen measuring interval and saved as one measuring value.

600 single measurements per second can be performed with the system's measuring frequency of 600 Hz. This results in 1350 single measurements per 50 m at a speed of 80 km/h, a single measurement is conducted every 37 mm. At a speed of 120 km/h, 900 single measurements or one measurement every 56 mm respectively are achieved.

5 Measuring location

Measuring location pertaining to paragraph 2.1: marking test field on the through road B 4 near Torfhaus (Oberharz): On this test field lie approx. 100 labelling test patterns, of type I and type II, applied to the direction of travel. Each test pattern consists of eight dashes according to the size of 2 metres of length x 0,15 metres of width.

Measuring location pertaining to paragraph 2.2: through road B 82 near Bad Harzburg. This through road is similar to the motorway, enlarged to four lanes.

6 Execution of the measurements

Measuring day: February 18, 2009. Road condition on B4: road and marking surface are slightly humid. Road condition B 82: dry.

The measuring head of the ZDR 6020 was installed on the vehicle before taking the measurements and adjusted in a way that, according to paragraph three, the measuring geometry was observed. Afterwards, the measuring system was calibrated by means of a marking film which was stuck to an even base. The comparative device ZRM 6013 was calibrated by means of the internal calibration standard.

6.1 Comparison of the measurements with a static measuring device

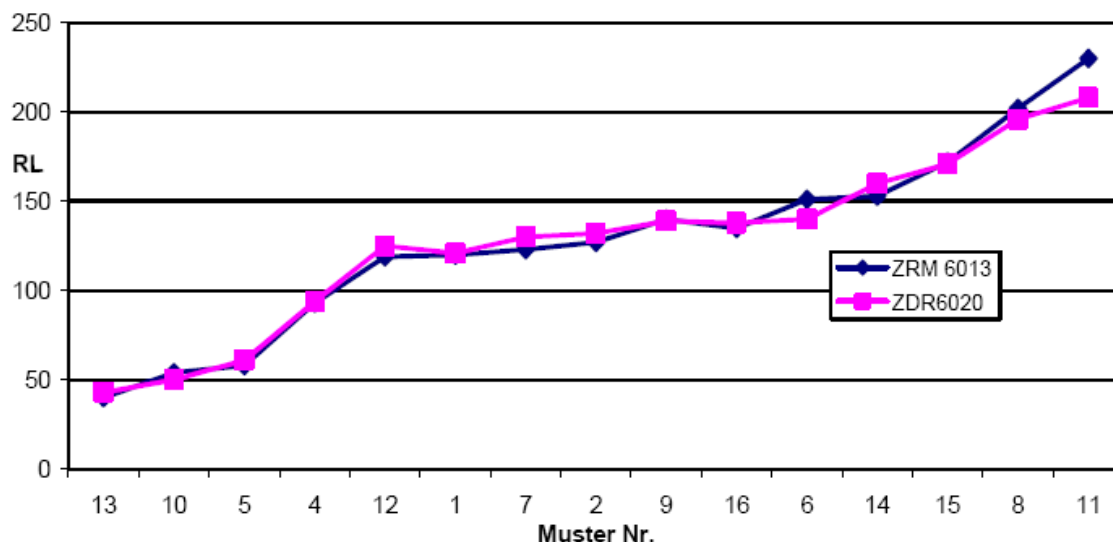
Of each type, I and II, one streak of 15 test patterns was measured immediately in a row, both with the ZDR 6020 (walking speed) and the retroreflectometer ZRM 6013, on the test field Oberharz. Table 1 shows the measuring values M_{ZDR} and M_{ZRM} for all streaks for both measuring systems, the common average value M , composed of M_{ZDR} and M_{ZRM} , as well as the percentage deviation of the measured value of the ZDR 6020 from the common average value: $M_{ZDR}/M \cdot 100 \%$. Picture 1 shows the measuring values M_{ZDR} and M_{ZRM} for the 15 test patterns.

Type I: G: smooth marking
Type II: A1: large, erratical agglomerates (s. Appendix, Picture A.1)
A2: small erratical agglomerates (s. Appendix, Picture A.2)
A3: large regular agglomerates (s. Appendix, Picture A.3)
A4: small regular agglomerates (s. Appendix, Picture A.4)
F: Foil, diamond-shaped embossing

Pattern No.	Marking type	M_{ZRM}	M_{ZDR}	M	$M_{ZDR}/M \cdot 100 \%$
13	G	40	43	41,5	3,5
10	A4	54	50	52	-4,0
5	A4	58	61	59,5	2,5
4	G	93	94	93,5	0,5
12	A2	119	125	122	2,4
1	G	120	121	120,5	0,4
7	G	123	130	126,5	2,7
2	G	127	132	129,5	1,9
9	A1	140	139	139,5	-0,4
16	A1	135	138	136,5	1,1
6	G	151	140	145,5	-3,9
14	G	153	160	156,5	2,2
15	A3	172	171	171,5	-0,3
8	G	202	196	199	-1,5
11	F	230	208	219	-5,3

absolute average deviation			2,2
average value	127,80	127,20	

Table 1: Measuring results of the test field



Picture 1: Comparison of RL-values MZDR and MZRM for both measuring systems, test field Torfhaus.

6.2 Comparison of the measurements at different measuring speeds

On the through road B 82, the coefficient of retroreflected luminance was continuously measured with the ZDR 6020 between two junctions on the right road margin, consisting of a streak of 15 centimetre of width, in both directions at a velocity of approx. 50 km/h, 80 km/h and 100 km/h. The driving velocity was kept as constant as possible during the measurements. The measuring distance amounted to 2'050 km, respectively 2'150 km. Every 100 m there was taken the average and stored in the software. The pictures 1 and 2 show these average values for both directions. In direction A there was a wet spot on the marking, at approx. 650 m after the start. Therefore, the value for this measuring interval was not evaluated.

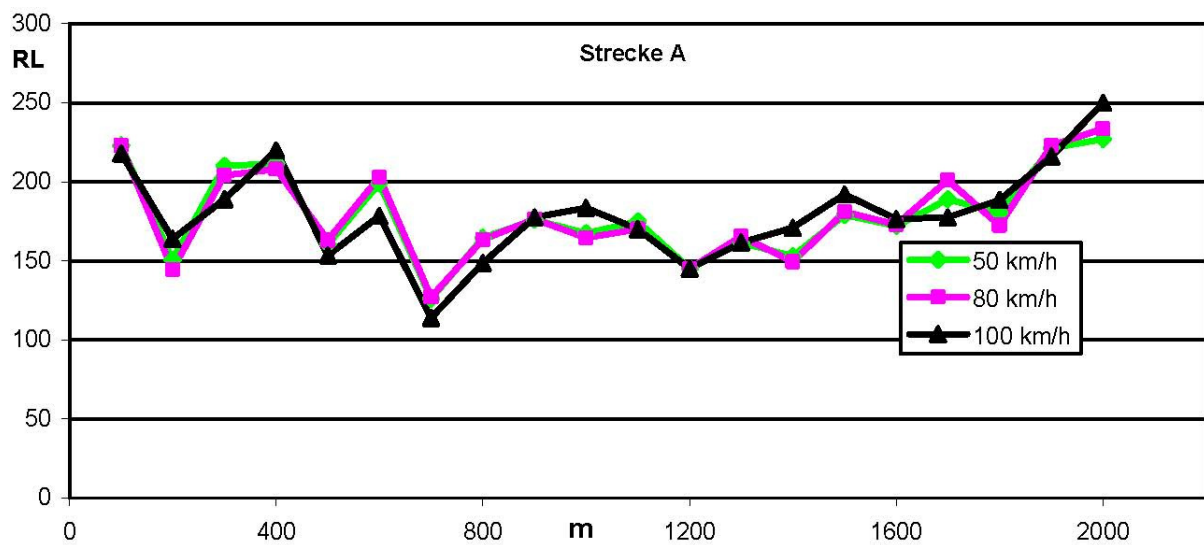
1	2	3	4	5	6	7	8
Measuring interval (m)	RL-average values MV over 100 m (mcd/m ² .lx)				Common average M		100 % · MV/M
	50 km/h	80 km/h	100 km/h	50 km/h	80 km/h	100 km/h	
100	223	223	218	221,3	0,8	0,8	-1,5
200	150,5	144,5	164	153,0	-1,6	-5,6	7,2
300	210	204	189	201,0	4,5	1,5	-6,0
400	211,5	208	220	213,2	-0,8	-2,4	3,2
500	160,5	163	153,5	159,0	0,9	2,5	-3,5
600	199	203	178,5	193,5	2,8	4,9	-7,8
700	126	127	114	122,3	3,0	3,8	-6,8
800	164,5	163,5	148,5	158,8	3,6	2,9	-6,5
900	176	176,5	177,5	176,7	-0,4	-0,1	0,5
1000	167,5	164,5	183,5	171,8	-2,5	-4,3	6,8
1100	175	170	170	171,7	1,9	-1,0	-1,0
1200	145	145	145	145,0	0,0	0,0	0,0
1300	161,5	165,5	161,5	162,8	-0,8	1,6	-0,8
1400	153	149,5	171	157,8	-3,1	-5,3	8,3
1500	179	181	192	184,0	-2,7	-1,6	4,3
1600	172	173	176,5	173,8	-1,1	-0,5	1,5
1700	189	201	177,5	189,2	-0,1	6,3	-6,2
1800	180,5	172,5	188,5	180,5	0,0	-4,4	4,4
1900	221,5	223	216	220,2	0,6	1,3	-1,9
2000	227	233,5	250	236,8	-4,2	-1,4	5,6

Table 2: RL-values in dependence of speed, average values over 100 m, route A

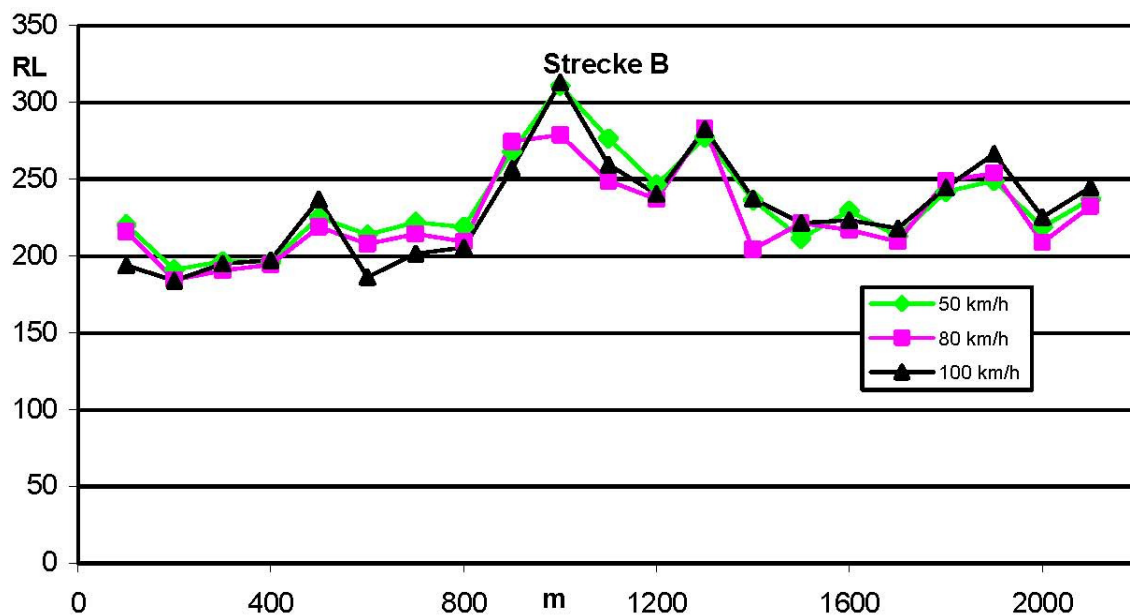
1	2	3	4	5	6	7	8
Measuring interval (m)	RL-average values MV over 100 m (mcd/m ² .lx)				Common average M		100 % · MV/M
	50 km/h	80 km/h	100 km/h	50 km/h	80 km/h	100 km/h	
100	220,5	216	194	210,2	4,9	2,8	-7,7
200	191	184,5	184	186,5	2,4	-1,1	-1,3
300	196,5	190,5	195	194,0	1,3	-1,8	0,5
400	196	194,5	197,5	196,0	0,0	-0,8	0,8
500	225,5	219	237	227,2	-0,7	-3,6	4,3
600	214	208	186,5	202,8	5,5	2,5	-8,1
700	222	214,5	201,5	212,7	4,4	0,9	-5,3
800	219	209,5	205,5	211,3	3,6	-0,9	-2,8
900	268	274,5	257	266,5	0,6	3,0	-3,6
1000	311	279	313	301,0	3,3	-7,3	4,0
1100	276,5	249	259,5	261,7	5,7	-4,8	-0,8
1200	246,5	237	240,5	241,3	2,1	-1,8	-0,3
1300	277,5	283,5	282,5	281,2	-1,3	0,8	0,5
1400	236,5	204,5	237,5	226,2	4,6	-9,6	5,0
1500	211,5	221,5	221,5	218,2	-3,1	1,5	1,5
1600	229,5	217	223,5	223,3	2,8	-2,8	0,1
1700	213	209,5	218	213,5	-0,2	-1,9	2,1
1800	242	249	244,5	245,2	-1,3	1,6	-0,3
1900	249	254	266,5	256,5	-2,9	-1,0	3,9
2000	219	209	225,5	217,8	0,5	-4,1	3,5
2100	237	232,5	245	238,2	-0,5	-2,4	2,9

Table 3: RL-values in dependence of speed, average values over 100 m, route B

Pictures 2 and 3 show the average values M_V for both routes.



Picture 2: Over 100 m averaged measuring values RL , measuring route A



Picture 2: Over 100 m averaged measuring values RL , measuring route B

The average values RL at the three measuring speeds for the whole measuring distance are arranged in table 2. Table 3 indicates the correlation coefficients r , which resulted out of the comparison of the measuring results for any two velocities.

route	Measuring speed (km/h)		
	50	80	100
	R _L (mcd/m ² .lx)		
A	179,6	179,6	179,7
B	217,1	210,8	214,4

table 4: R_L-average values at different measuring velocities

route	Comparison of the R _L -values at measuring speeds (km/h)		
	50 with 80	50 with 100	80 with 100
	Correlation coefficient r		
A	0,987	0,884	0,907
B	0,921	0,893	0,929

table 5: Correlation coefficient r at the comparison of the R_L-values, determined for different measuring velocities

7. Assessment of the measuring results

7.1 Assessment of the measurements with a static measuring device

Table 1 shows that the measured values of the ZDR 6020 differ from the common average value of both measuring systems at most with +3,5 % / -5,3 %. According to the validation process of the Federal Highway Research Institute (BASt) for road markings and measuring devices a variation of about $\pm 7,5$ % can appear in at most 5 % of all comparative values, this regulation is complied with the ZDR 6020. Averaged over all 15 patterns, both measuring systems provide practically identical measured values: M_{ZRM}: 127,8 mcd/m².lx; M_{ZDR}: 127,2 mcd/m².lx; the correlation coefficient r amounts to 0,991. This confirms that the measuring system ZDR 6020 provides, within the scope of an acceptable measuring accuracy, the same measured values of the coefficient of retroreflected luminance as a static, portable measuring device.

7.2 Evaluation of the measurements at different measuring velocities

Table 2 indicates that the measured values, averaged over the length of the distances, are practically identical at the three measuring velocities. The pictures 1 and 2 show the deviation of the over 100 m averaged measured values. The investigation of the percentage deviation from the common average value reveals that only in 4 of 123 measurement values (3,3 % of all cases), there is one single measurement value deviating from the common average value more than 7,5 %. Therewith BASt regulation is fulfilled (in at most 5 % of all comparative values a variance of more than $\pm 7,5$ % is allowed, mentioned in paragraph 6.1). The correlation coefficients for the difficult measuring conditions in moving traffic are acceptable.

The coefficient of retroreflected luminance (night visibility R_L) can be detected with an acceptable measuring accuracy by the measuring system of the ZDR 6020, independent of the measuring velocity.

7.3 Overall assessment

The retroreflectometer ZDR 6020 is applicable for the dynamic measurement of the coefficient of retroreflected luminance (night visibility R_L) of road markings, independent of velocity and it provides the same measuring results as a static, portable retroreflectometer.

Dr. H. Meseberg
Chairman StrausZert

This test certificate has been issued in all conscience.

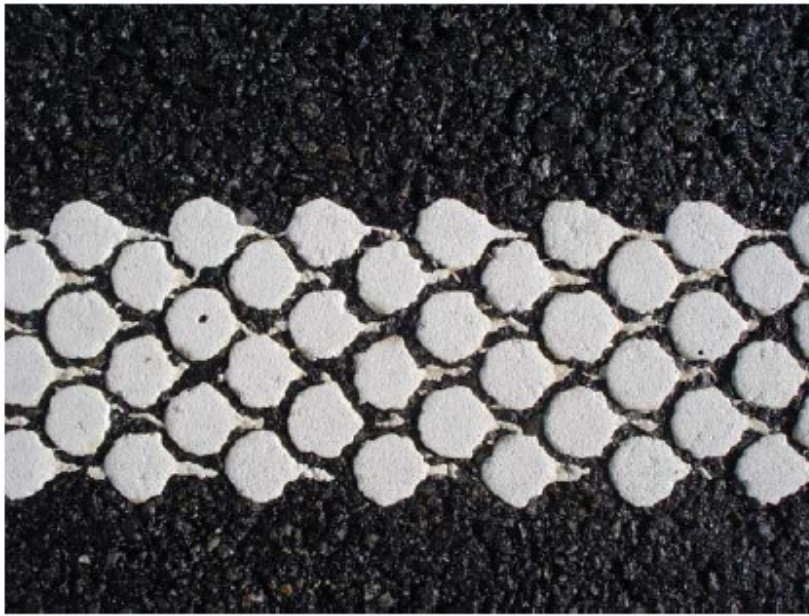
Appendix: pictures of the marking samples on the test field



Picture A1: large, erratical agglomerates



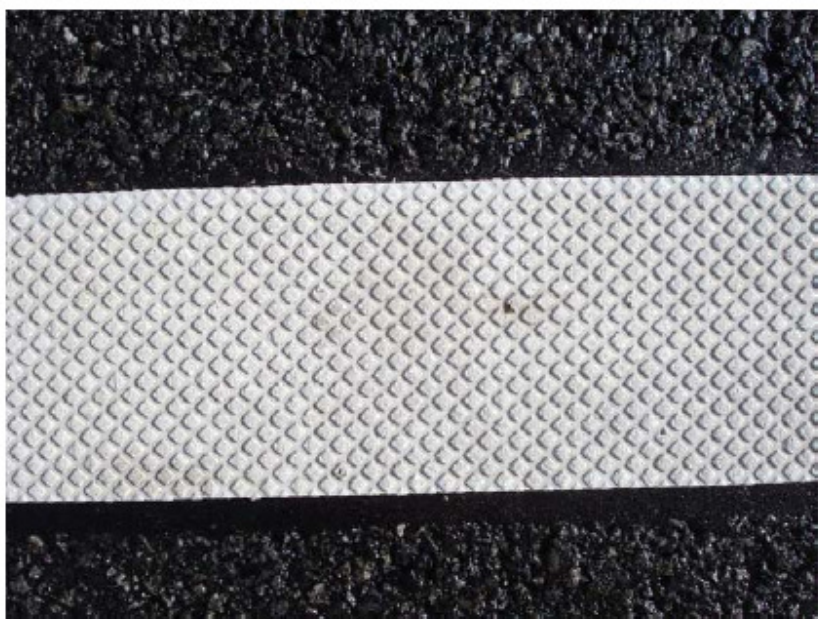
Picture A2: small erratical agglomerates



Picture A3: large regular agglomerates



Picture A4: small regular agglomerates



Picture A5 Foil, diamond-shaped embossing

Traffic standards and guidelines
2003/2004 survey

RSS 22

Road markings

August 2004

Survey of traffic standards and guidelines

The Land Transport Safety Authority (LTSA) is the government agency responsible for *promoting safety in land transport at reasonable cost*. Part of its function is to ‘monitor adherence to safety standards within the land transport system’.

To support this objective, the regional engineering sections of the Land Transport Safety Authority undertake a survey programme that assesses the effectiveness of the implementation of various safety standards by road controlling authorities.

The purpose of these surveys is to:

- assist and advise road controlling authorities on the implementation of selected traffic standards and guidelines that affect traffic safety
- measure the uptake of standards and guidelines by road controlling authorities
- provide a national summary of the uptake and compliance with standards and guidelines, and report findings to road controlling authorities and other interested parties
- identify changes to improve standards, guidelines or traffic rules.

The surveys are usually carried out in two parts:

- Part 1 uses a questionnaire to look at the systems and procedures a road controlling authority has in place to deliver on the standard.
- Part 2 uses a field survey to measure, where possible, the actual delivery from the user’s viewpoint. It essentially provides a snapshot of road safety delivery at the date of the survey.

This report presents the national results of the latest of these surveys.

I believe you will find the information of value and will be able to use it to improve road safety in New Zealand.

Please contact the nearest regional office of the LTSA if you would like further information, or assistance with implementing traffic standards or guidelines.



John Kay
General Manager Operations

Contents

Executive summary	i
1 Introduction	1
2 Purposes of the survey.....	1
3 Methodology.....	1
3.1 Sample selection.....	1
3.2 Interview surveys.....	2
3.3 Field surveys.....	2
4 Results of the interview surveys	3
4.1 Road networks	3
4.2 Road marking standards	4
4.3 Reviewing road marking	7
4.4 Road marking materials.....	7
4.5 Wet/night visibility assessment	8
4.6 Skid resistance assessment	8
4.7 Road marking materials and trial opportunities	8
4.8 Subdivision road markings	9
4.9 Road marking database.....	9
4.10 Public enquiries and concerns	10
4.11 Management of road marking programme	10
4.12 Contract terms, specifications and quality control	10
4.13 Testing and other contract management procedures	12
4.14 Traffic management requirements.....	15
4.15 Rating of contractors' performance and traffic management.....	15
5 Results of the field surveys.....	16
5.1 Survey sample	16
5.2 Line widths	17
5.3 Daytime visibility	17
5.4 Night-time visibility	17
5.5 Observations	19
6 Discussion	20
6.1 General	20
6.2 Best practice	21
7 Recommendations.....	22
Appendix 1: Summary of field surveys, by RCA.....	23
Appendix 2: Survey of road markings – Questionnaire.....	25
Road safety survey series	31

List of abbreviations

MOTSAM	<i>Manual of traffic signs and markings: Part II: Markings (TNZ/LTSA, 2004)</i>
CoPTTM	<i>Code of practice for temporary traffic management</i>
M/20	<i>TNZ M/20 Long-life roadmarking materials</i>
M/7	<i>TNZ M/7 Roadmarking paints</i>
P/12	<i>TNZ P/12 Pavement marking</i>
P/20	<i>TNZ P/20 Performance-based specification for roadmarking</i>
P/22	<i>TNZ P/22 Specification for reflectorised pavement marking</i>
RSS 13	<i>Road safety survey 13: No passing lines (LTSA, 2000)</i>
RTS 5	<i>Road and traffic standards series 5: Guidelines for rural road markings and delineation (TNZ/LTSA, 1992)</i>
TNZ	Transit New Zealand
NZRMF	New Zealand Roadmarkers Federation
RCA	road controlling authority
TLA	territorial local authority

Executive summary

Introduction

Surveys were undertaken during 2003/04 to investigate policies and practices for traffic calming devices and road markings in a sample of road controlling authorities (RCAs).

This report describes the procedures and presents the results for the road markings surveys. A companion report (RSS 21 *Traffic calming*) details the results of the surveys on traffic calming devices.

The road marking surveys were undertaken between mid-November 2003 and mid-February 2004. This coincided with the season for remarking work.

Methodology

Interviews

The Land Transport Safety Authority (LTSA) interviewed staff in 33 road controlling authorities about their policies and practices. The RCAs received a copy of the questionnaire in advance, to help them prepare their responses.

Alister Harlow, Executive Director of the New Zealand Roadmarkers Federation (NZRF), assisted with the interviews.

Field surveys

After the interviews, the surveyors, including Alister Harlow, joined with staff from the RCAs to inspect a representative, on-road sample of road markings. A total of 643 lines were surveyed at 221 sites (126 urban, 95 rural) in the 33 RCA regions. The surveyors measured line widths and day and night-time visibility.

The results were assessed against the performance criteria in TNZ P/20 *Performance-based specification for roadmarking*. (The results are detailed in Section 5.1 of this report.) The performance criteria were not contractual requirements, in most cases.

Interview results

- Rural roads made up more than 70% of the total length of the sealed networks in most of the RCAs surveyed. However, 6 large urban authorities, with urban roads typically comprising more than 80% of their sealed networks, were also in the survey.
- The TNZ/LTSA *Manual of traffic signs and markings: Part II: Markings* (MOTSAM) was used by all the RCAs surveyed as their guideline on what road markings are required. 22 (67%) of the RCAs also used *Road and traffic standards series 5: Guidelines for rural road marking and delineation* (RTS 5), or a local modification of RTS 5.

- The most common catalysts for changes to road marking design or the frequency of road markings were road inspections, reviews or audits (in 14 (42%) of the RCAs) and crash reduction studies (in 11 (33%)).
- All except 2 of the RCAs used TNZ specifications for road marking materials, with paint systems being the most predominant method used.
- The use of reflectorised markings varied:
 - 16 (48%) of the RCAs used reflectorised paint for most of their markings.
 - 3 (9%) used reflectorised paint for markings on specific classes of road.
 - 7 (21%) used reflectorised markings in accordance with MOTSAM¹.
 - The other 7 (21%) used minimal or no reflectorised markings.

The Traffic Regulations 1976 require reflectorised markings for kea crossings (T Reg 96A(4)(a)) and for the RAIL X markings at level crossings (106(6)(a)).

- Most of the RCAs (27, or 82%) stated that they welcome opportunities for materials trials on their networks. Thermoplastic was identified as the long-life material of choice for 4 large authorities for their urban arterials and high-wear areas. The RCAs indicated that there might be more use of thermoplastic if there was more locally available application equipment.
- All except 3 of the RCAs had some form of database for their road markings, with the most common being RAMM (used by 19 of the RCAs (58%)).
- Most of the RCAs (23, or 70%) had method-based road marking contracts, and all of the RCAs used TNZ specifications.
- Remarking programmes for the method-based contracts were based on time periods ranging from every 6 months to every 18 months. Most of the programmes (74%) were based on annual remarking, or annual plus 6-monthly remarking for high wear markings.
- 3 RCAs were using or trialling remarking periods based on visual needs assessments. One of these RCAs claimed they were getting up to 3 years' life on some markings on low volume roads.
- Nearly half the RCAs (15, or 45%) used blacking out to remove small amounts of unwanted markings. More common was the use of sand or abrasion blasting (used by 19 RCAs, or 58%), although this was sometimes restricted until there was sufficient work to warrant a contract. Similarly, 14 RCAs (42%) used water blasting.
- All RCAs rated their contractor's general performance and traffic management as *acceptable or better*.

¹ MOTSAM particularly specifies reflectorised materials for some road markings and allows discretion for using reflectorised materials on other markings. The most used markings that are specified to be reflective in MOTSAM are no overtaking (no passing) lines, limit lines, and flush medians.

Field survey results

- 73% of the 631 line widths that were checked were within the specified tolerance for line widths. 15% were wider than the upper tolerance limit and 12% were narrower than the lower tolerance limit.
- 99% of the 551 lines that were assessed for daytime visibility met the 150 m forward visibility criteria.
- A wide range of night-time visibility performance was indicated by the reflectivity measurements. Readings were taken on both reflectorised and non-reflectorised markings, to enable comparison.

Reflectivity measurements were taken on 808 markings and assessed against the TNZ P/20 intervention or performance-level criteria. This performance measure was not a contractual requirement in most cases.

The assessment showed the following percentages as being *at or above* the performance measure:

- 45% of all 808 measurements
- 68% of the 166 measurements taken at sites in areas marked under performance-based contracts
- 67% of the 493 measurements on lines recorded as being reflectorised, or specified to be reflectorised
- 76% of the 30 measurements taken on limit lines and 58% of the 86 measurements taken on no passing lines. (MOTSAM specifically requires both these line types to be reflectorised)
- 88% of the 16 measurements taken on thermoplastic lines
- 75% of the 102 measurements taken on smooth surfaces (compared with 41% of the 705 measurements taken on chip seal surfaces).
- Very few examples of unexpected or non-standard markings were observed, either at the sites or when driving between the sites.
- Blacked-out markings at one site were noted to have reflectivity measurements near and above the performance measure. These markings would be very misleading at night and potentially unsafe.

Best practice

The surveyors consider that best practice includes:

- adopting clear policies on what markings to use on which roads
- maintaining a good database of road markings
- having remarking programmes based on assessed needs
- having formal customer service request systems

- developing good contractual relationships that allow trials, to increase knowledge and ensure continuous improvement of the performance of road marking
- using reflectorised markings to improve the night-time visibility of markings, especially no passing lines and centre lines
- carrying out complete reseals to remove unwanted markings, if removal by blacking out or abrasion blasting could result in unsafe delineation
- supervision of road marking contracts using industry-developed guidelines and quality assurance records.

The degree to which these elements are adopted depends on the road marking budget and the RCA determining that they will obtain value for the likely costs.

Recommendations

- RCAs should continue to work with their road marking contractors to apply best practice and to undertake trials to increase knowledge and ensure continuous improvement in the level of service from road markings.
- The requirements for reflectorised markings should be reviewed. More use of reflectorised markings could improve night-time safety.
- The removal of unwanted markings by blacking out or abrasion blasting should be limited to small amounts of this work and locations where ineffective removal will not create a safety problem. Resealing should be used for large amounts of this work or where safety problems could be created.
- The LTSA should, through its Standards and Guidelines Steering Group, promote the development of guidelines for road marking on private land areas that have public access and road-type use.
- RCAs should assess whether they can achieve better value from remarking programmes based on an assessment of needs, rather than simply carrying out time-based remarking of all existing markings.
- The NZRF should continue to promote best practice and develop guidelines to assist RCAs to get the best value from their road marking programmes.

1 Introduction

Between November 2003 and February 2004, the regional offices of the Land Transport Safety Authority (LTSA) conducted surveys of traffic calming devices and road markings in a sample of road controlling authorities (RCAs).

This report describes the procedures and presents the results for the survey of road markings. The road marking surveys coincided with remarking work having recently been undertaken in many areas, because the season for such work had just passed.

Alister Harlow, Executive Director of the New Zealand Roadmarkers Federation (NZRF), assisted with the road marking survey. The involvement of the NZRF stimulated discussion and helped promote good ideas and best practice for road marking. The NZRF provided a MX30 retroreflectometer for undertaking retroreflectivity readings on road markings during the field surveys.

2 Purposes of the survey

The purposes of the survey were to:

- identify RCA network characteristics and road marking policies
- establish what standards and guidelines were being used by RCAs for the provision of road markings
- establish what contractual procurement and management procedures were being used by RCAs to manage their road marking
- take a snapshot of the standard of markings at randomly selected sites, and compare them with recognised performance criteria
- identify aspects of the provision and maintenance of road markings that could be improved, and recommend appropriate remedial action.

3 Methodology

3.1 Sample selection

A sample of 33 RCAs was chosen for the surveys. This included 29 territorial local authorities (TLAs) and four regional offices of Transit New Zealand (TNZ). The sample was weighted towards authorities not included in the 2002/2003 LTSA surveys. Six of the territorial local authorities covered major urban areas. Four covered large provincial townships, with more than a quarter of their sealed roads being urban. The other 19

TLAs covered rural areas with small provincial towns. The surveys of Transit New Zealand regions focused on one professional service contract area per regional office.

Appendix 1 lists the 33 RCAs included in the surveys.

3.2 Interview surveys

Interview surveys were conducted with representatives of each of the 33 RCAs. Survey forms were sent in advance, to give the RCAs time to research answers, where necessary. Questions were centred on the standards, guidelines, programmes and practices used for the provision of road markings.

The questionnaire used for the interview surveys is shown in Appendix 2.

3.3 Field surveys

Field surveys were conducted for all except one of the 33 RCAs, and staff or representatives from each RCA were encouraged to accompany the surveyors.

The field surveys aimed to determine the extent to which samples of road markings on a RCA's roads complied with:

- *either* the Transit New Zealand/Land Transport Safety Authority *Manual of traffic signs and markings: Part II: Markings* (MOTSAM), *or*
- any policies and procedures adopted by the specific local authority and stated in their response to the questionnaire, *and*
- performance criteria for line width, daytime visibility and night-time visibility.

Sites were selected by driving along a sample of level 1 type roads (traffic volume 500 to 10,000 vpd) and stopping at sites that were typical of the general condition of road marking on the route, and where it would be safe to take the measurements. The sites selected were more often on straight sections of roads than on bends. Sites where there was obvious damage to the road markings or where there was high wear (such as on routes to industrial areas) were avoided.

In the regions of each of the major urban authorities, about six urban sites were selected. In the regions of each of the other authorities, about four urban and four rural sites were selected.

Generally, line widths, daytime visibility assessments and reflectivity readings were taken on all lines at each site. At least *three* reflectivity readings were taken along a few metres of each line. Five or seven readings were taken if there was inconsistency in the readings. If the surface type varied at a site, readings were taken separately on each surface type, or just on one surface type.

The performance measurements were used to give a snapshot of the markings at the time of the survey. They were not used to measure or compare contractors' performances. The performance measures were not contractual criteria, in most cases.

4 Results of the interview surveys

4.1 Road networks

Length and surface types

Twenty seven of the 33 RCAs completed question 1, detailing the lengths of urban and rural sealed roads and the type of sealed surface.

- 4 were large urban authorities and their responses showed that more than 80% of the length of their sealed roads was *urban*.
- Responses from the other 23 RCAs showed that 70% or more of the length of each of their networks was *rural*.
- In addition, the responses from the 27 RCAs showed the following:
 - 78% of the urban sealed roads have chip seal, 19% smooth asphalt type surfacing, and 2% ‘other surfaces’ (such as concrete or brick paved areas).
 - All except about 1% of the total length of rural sealed roads have chip seal surfacing.

Special conditions affecting road marking

The most common conditions affecting road markings were:

- gritting for ice – 16 (48%) of the RCAs
- snow – 4 (12%)
- seal bleeding (weather or heavy traffic) – 9 (27%).

Other conditions recorded included stock effluent, rock falls, forestry traffic and heavy vehicle use. One of the respondents noted that some research suggests marking too soon after CMA application reduces the life of the markings.

Delegated authority

- None of the authorities surveyed had delegated authority for road markings on any significant sections of another authority’s road network.
- 7 (21%) RCAs noted they had authority for marking on boundary roads, or marking parking and no stopping restrictions on state highways.

Typically, limit lines and other intersection markings on local roads at state highway intersections are marked by the state highway road marking contractor.

4.2 Road marking standards

General

- All of the RCAs surveyed used MOTSAM to determine what road marking was required.
- 22 (67%) RCAs also used *Road and traffic standards series 5: Guidelines for rural road marking and delineation* (RTS 5), or a local modification of it.

Centre lines and edge lines

Responses to the questions on the *criteria for marking centre lines and edge lines* were incomplete. Typically the replies noted the inter-relatedness of the criteria for traffic volumes, road classification and road width. However, there was no obvious commonality or definitive criteria discernible from the responses.

- The proportion of the local authority networks marked with *centre lines only* varied from 4% to 50%; and the proportion marked with *edge and centre lines* varied from 3% to 42%.
- Only a few authorities provided data on the road lengths marked with *edge lines only* and these indicated that less than 10% of their networks were marked with edge lines only.
- All 4 TNZ areas surveyed had both centre and edge lines (or kerbs) on the full network.

The responses indicated that a variety of *line widths* are used by the RCAs for both centre and edge lines. The following widths are used:

- 75 mm centre line – 3 (9%) RCAs
- 100 mm centre line – 29 (88%) RCAs
- 75 mm edge lines – 12 (36%) RCAs
- 100 mm edge lines – 23 (70%) RCAs
- 150 mm or 200 mm spot treatments for edge and/or centre lines – 8 (24%) RCAs
- 2 (6%) of the RCAs simply quoted MOTSAM for line widths.
- 1 (3%) of the RCAs indicated that they use a variety of line widths, but did not specify what widths.

Some RCAs use more than one width for edge and/or centre lines, so the numbers above do not add up to the 33 RCAs surveyed.

MOTSAM was referred to as the guideline. Section 2.01.02 of MOTSAM specifies that standard urban and rural road centre lines should be 100 mm wide. Section 2.03.02 specifies 75 mm-wide edge lines for two-lane rural roads with an AADT < 2500; and 100 mm-wide edge lines for two-lane rural roads with an AADT > 2500, and for two-lane urban roads.

Other road markings

Question 7 of the questionnaire was intended to identify specific situations or road markings where RCAs might use local standards or variations from MOTSAM. Various road markings were listed in the question. Unfortunately, the question was ambiguous and some authorities only responded if they used a variation from MOTSAM for the listed road marking, and others if they used the listed marking either in accordance with MOTSAM or to a different standard. Responses, therefore, do not add up to the 33 RCAs surveyed. Analysis of the responses shows the following trends:

Flush medians

- 21 (64%) of the RCAs indicated that they have flush medians and mark them in accordance with MOTSAM. 3 (9%) of these have no gap in the median at minor side road intersections. (Diagrams in MOTSAM show flush medians with a gap and continuity lines across intersections. However, MOTSAM does note that they may be marked straight through minor side roads that have very low turning flows.)

Painting of kerbs on traffic islands

- 20 (61%) of the RCAs paint kerb faces on the noses of traffic islands and another 3 (9%) no longer paint them, but have done so in the past. (MOTSAM notes that kerb faces may be marked with reflective white material.)
- Of the 20 RCAs that paint the kerb faces:
 - 6 painted just the nose end of traffic islands
 - 2 painted the full islands (generally, to give an overall tidy appearance in urban areas)
 - 12 did not state whether they painted only the nose or the full island.

Comments noted during the surveys identified:

- maintenance issues to do with keeping paint markings in good condition on the concrete kerb surfaces
- that RG 17 'Keep left' signs on traffic islands are the signs most often replaced because of damage.

Right turn bays

- 23 (70%) of the RCAs stated that they have painted right turn bays, marked in accordance with MOTSAM. Generally the full chevron marking is used, but 7 of these RCAs had also used the MOTSAM urban alternative when space was limited.

One authority commented that the installation of cycle lanes was reducing the space for right turn bays.

Private land (service stations, shopping car parks, etc)

- 24 (73%) of the RCAs stated that the marking at public access intersections to private land (eg, service stations, supermarket car parks) is controlled through District Plan or resource consent procedures. The other 9 (27%) RCAs either did not answer, or answered 'No' or 'Not applicable' to this question. Generally, the

developer was responsible for any markings on the private land, and the road controlling authority for markings on the road.

- Similarly, 24 (73%) of the RCAs stated that they had engineering input, through the District Plan or resource consent process, into what markings might be used on private land that has public access, but the developer or land owner was responsible for the markings. Again, the other 9 (27%) either did not answer or answered ‘No’ or ‘Not applicable’ to this question.
- Control of markings on public access private land was mainly an issue in the larger urban authorities, with inconsistency in the standards being applied noted as the main problem. One authority suggested the LTSA should assist in developing national standards for parking areas. The interviews showed some support for this, but the level of support was not recorded.

Pedestrian crossings

- 7 (21%) of the RCAs stated that they mark limit lines at pedestrian crossings.
 - 2 of these mark *all* crossings with limit lines.
 - 3 mark *some* of their crossings.
 - 1 had tried them at one crossing but found they were not useful.
 - The other RCA was implementing an upgrading to mark limit lines and centre lines at all crossings.

Lane arrows for tourists

- 7 RCAs (21%) stated that they use lane arrows to help direct tourists to drive on the left.
- A further 3 stated that they were considering using them on some tourist routes.

Two formats for their use were evident: placing the arrows in pairs (one in each lane), or having the arrows staggered. It was considered the arrows in pairs had greater impact and gave a clearer message to tourists to drive on the left. The staggered layout was developed to overcome legal issues near access points where the arrows in pairs may be interpreted as meaning drivers could not turn into the access, as they would be failing to comply with the lane markings.

‘Keep clear’ zones

- 11 (33%) of the RCAs use hatch markings to indicate ‘Keep clear’ zones.
- 3 (9%) use *either* hatched markings *or* the words ‘Keep clear’.
- 1 (3%) uses just the words.

Alberta markings at multilane roundabouts

- 28 (85%) RCAs did not have multilane roundabouts.
- 5 (15%) RCAs had multilane roundabouts and all of these used Alberta type markings.

4.3 Reviewing road marking

Processes that caused changes in road marking design or the frequency of road marking were:

- road inspections, reviews or audits – 14 (42%) of the RCAs
- crash reduction studies – 11 (33%) of the RCAs
- public complaints/requests, political pressure (to change frequency) and weather problems – 1 or 2 RCAs.

RCAs were asked whether they had reviewed their no passing line markings as a result of *Road safety survey 13: No passing lines* (RSS 13) (LTSA, 2000). Responses were:

- ‘No’ – 22 (67%). 2 of these RCAs noted that they had reviewed no passing lines as part of other inspections, but not as a result of RSS 13.
- ‘Yes’ – 11 (33%), including 1 RCA that was also investigating using no passing lines on horizontal curves.

4.4 Road marking materials

- 31 (94%) of the RCAs used either the specifications for road marking materials in TNZ M/7 *Roadmarking paints* and/or those in TNZ M/20 *Long-life roadmarking materials*.
- 2 (6%) of the RCAs stated that they specified ULTRAX, a polymer-modified alkyd paint.

Reflectorised markings were specified by authorities:

- for all markings, or all except no stopping and parking – 14 RCAs (42%)
- for all longitudinal markings, but not limit lines or arrows – 1 RCA (3%)
- for as many markings as possible – 1 RCA (3%)
- for rural centre and edge lines and pedestrian crossings – 1 RCA (3%)
- for limit lines plus arterial or strategic roads – 1 RCA (3%)
- for high volume arterials or collectors – 1 RCA (3%)
- as MOTSAM² specifies – 7 (21%) of the RCAs, including 1 RCA that also specified reflectorised markings for some collectors
- for limit lines, no passing lines and pedestrian crossings – 2 RCAs (6%)
- for give way lines, stop lines, one-lane bridges and no passing lines – 1 RCA (3%)
- for controlled intersections – 1 RCA (3%).

² MOTSAM particularly specifies reflectorised materials for some road markings, and allows discretion for using reflectorised materials on other markings. The most used markings that are specified to be reflective in MOTSAM are no overtaking (no passing) lines, limit lines, and flush medians.

Three RCAs (9%) do not use, or do not specify, reflective materials.

The Traffic Regulations 1976 require reflectorised markings for kea crossings (T Reg 96A(4)(a)) and for the RAIL X markings at level crossings (106(6)(a)).

4.5 Wet/night visibility assessment

- 13 (39%) of the RCAs reported undertaking night-time inspections, but not specific wet/night assessments.
- 19 (58%) reported that they do not undertake wet/night assessments.
- 1 of the TNZ regions noted that their consultant and contractor undertake reflectivity tests for dry night visibility.

4.6 Skid resistance assessment

- 30 (91%) of the RCAs said they do not undertake skid resistance tests of their road markings.
- 3 (9%) reported undertaking skid resistance tests for road markings. 1 had undertaken British Pendulum tests near the start of the contract term and had not repeated them because they demonstrated compliance considerably exceeding the requirements. Another noted they were part of P/20, and the third did not give any details of the tests they carried out or when they were undertaken.

4.7 Road marking materials and trial opportunities

Paint systems are the most predominant material used for road markings.

- 16 (48%) of the RCAs said they specify materials complying with the M/7 specification and have markings made using standard alkyd paint.
- 14 (42%) of the RCAs specify waterborne materials, with 5 of these providing for the use of alkyd materials when the application conditions are not suitable for the waterborne.
- 2 (6%) of the RCAs use a polymer-modified alkyd paint.
- 1 (3%) of the RCAs did not specify the materials, as this is their contractor's selection under their performance-based contract.

Responses to the question about long-life products being used showed the following:

- Thermoplastic is the long-life material of choice for urban arterials and areas of high wear in North Shore, Auckland, Manukau and Wellington.
- A further 6 RCAs had trialled thermoplastic for pedestrian crossing, limit line or profiled edge line markings, as a safety enhancement.

RCAs indicated there might have been more use of thermoplastic if there was more local-based application equipment.

- Cold-applied plastic is being trialled by 3 RCAs (Far North District, Whangarei District and Hamilton City) on limit lines in high-wear areas.

A wide variety of marking systems are being used in the TNZ performance-based contracts.

Most of the RCAs (27, or 82%) stated they would welcome opportunities for materials trials on their networks.

4.8 Subdivision road markings

- 15 (45%) of the RCAs stated that control of road markings for new subdivisions was through the District Plan and the resource consent process.
- 8 (24%) of the RCAs stated that control was through their specifications or codes of practice.
- 9 (27%) said subdivision road marking was not applicable because they had few new subdivisions, or those they had did not require any road marking.
- 1 (3%) said that control was undertaken on a case-by-case basis.
- 6 (18%) of the RCAs indicated that they had problems with developers installing non-standard markings. The problems noted included poor advice from consultants, resulting in wrong markings at islands; cheap paint being used on roads to be taken over by the RCA; and there were a few instances of developers not following the council's development manual.
- One of the large urban authorities noted problems resulting from the number of council departments that could be involved in subdivisions, and the difficulty training all staff involved to check everything thoroughly. Another noted that they had a specific engineering team responsible for managing the development of subdivisions.

4.9 Road marking database

Six authorities reported having more than one type of database (eg, RAMM and spreadsheet or contractors' database). The types of database identified were:

- RAMM – 19 (58%) of the RCAs
- Excel spreadsheet or electronic database – 10 (30%) of the RCAs, including 1 using a total inventory system (MAXIMO)
- contractors' database – 5 (15%) of the RCAs
- no formal database – 3 (9%) of the RCAs (including 1 that was developing a database).

Maintenance and updating of the databases was mainly based on contractor's claims for payment, which typically involved Excel spreadsheets. For RCAs using consultants, responsibility for maintenance of the databases rested with the professional services consultants. Eleven (33%) RCAs updated their databases from cyclic surveys of the

network. Other systems for recording road markings included aerial photographs, GIS data and annual videotaping.

4.10 Public enquiries and concerns

- 27 (82%) of the RCAs had formal customer service request systems or procedures in place for receiving and handling public enquiries or concerns.
- 3 (9%) of the RCAs noted that they received very few complaints or concerns.
- 3 (9%) of the RCAs said that any concerns were investigated by engineering staff.

About half the RCAs directly issued instructions to contractors for any remedial works required. The other half used their consultants or design services sections to instruct contractors to undertake remedial works.

4.11 Management of road marking programme

RCAs indicated that management of the road marking programme was undertaken by:

- a professional services consultant – 14 (42 %) of the RCAs, including 1 that responded: ‘Asset manager plus professional services consultant’
- a council engineer or asset manager – 12 (36%) of the RCAs
- a council business unit or in-house consultant – 7 (21%) of the RCAs.

4.12 Contract terms, specifications and quality control

Contract terms and age

- Contract terms were:
 - 3 + 1 + 1 years – 12 (36%) of the RCAs
 - 2 + 1 + 1 + 1 years – 5 (15%)
 - 3 years – 4 (12%).
- 1 TNZ contract was a 10-year performance specification maintenance contract (PSMC), and another a 5-year hybrid contract.
- Other contract terms ranged from 1 to 3 years, with various fixed-term renewal periods – 10 (30%) of the RCAs.

At the time of the survey, contracts had been let for:

- more than 6 months – 27 (82%) of the RCAs
- 3 to 6 months – 3 (9%)
- less than 3 months – 4 (12%).

One RCA had more than one road marking contract.

Changes to the management contracts

- 17 (52%) of the RCAs had not recently investigated or changed their management of road marking contracts.
- 16 (48%) had recently investigated or were investigating a change, and of these:
 - 4 (12%) of the RCAs had recently changed
 - 2 (6%) had investigated but did not change
 - 10 (30%) were still investigating changes.

Method- or performance-based contracts

- 23 (70%) of the RCAs had method-based contracts.
- 10 (30%) had performance-based contracts.

Typically, the *method-based contracts* required materials application rates in accordance with TNZ P/12 *Specification for pavement marking* (150 microns dry film thickness, 275 grams/m² minimum bead drop-on rate). Five RCAs noted that they require 220 micron dry film thickness.

Performance criteria for seven of the *performance-based contracts* were based on TNZ P/20 *Performance-based specification for roadmarking* (colour, daytime visibility, night-time visibility, skid resistance). The other performance-based contracts included criteria such as 80% retained after 6 months, condition rating based on forward visibility (safety oriented), level of service, and no environment or health and safety incidences.

Specifications

- 26 (79%) of the RCAs indicated that they use the TNZ P/12 specification. (Most use the current 2000 version, but some use the 1995 or 1998 versions.)
- 2 RCAs (6%) said they use TNZ P/22 *Reflectorised pavement marking*.
- 5 RCAs (15%) said they use TNZ P/20.

Contract relationship

- 20 (61%) of the RCAs considered they had a *service agreement* type relationship with their contractor.
- 12 (36%) said they had a *partnering type* relationship.
- 1 (3%) RCA was unclear, as the terminology in their contract was vague.

One authority commented that partnering, with its three-way partnership between the council, consultant and contractor, provided more flexibility and innovation.

Quality assurance requirements

- 25 (76%) of the RCAs indicated that their quality assurance requirements were based on TNZ P/12, P/22 or P/20 specifications (specifically, ISO 9000: 2000).

- 5 (15%) used Transit New Zealand quality assurance requirements (TQS2 or TQS3).
- 2 (5%) use NZRF quality assurance requirements.
- 2 (5%) did not state their requirements

Remarking programmes

The 23 RCAs with method-based contracts used the following types of remarking programme:

- Annual remarking – 9 (39% of the 23 RCAs)
- Annual remarking, with 6-monthly for high-wear markings – 8 (35% of the 23 RCAs)
- 18-monthly remarking, with 6-monthly for high-wear areas – 1 (4% of the 23 RCAs)
- 9-monthly remarking – 1 (4% of the 23 RCAs)
- 6-monthly remarking – 1 (4% of the 23 RCAs)
- Needs-based remarking – 3 (13% of the 23 RCAs). 1 of these RCAs was trialling needs-based assessments to set the remarking programme. Another noted they were getting up to 3 years life on some markings on low volume roads.

The percentages shown above are based on the 23 RCAs with method-based contracts. Remarking programmes, and the period between remarking, are not applicable for the 10 (30%) of the RCAs surveyed that have performance-based contracts, as remarking is based on performance criteria.

4.13 Testing and other contract management procedures

Materials and application rate tests

Responses to questions 35 and 36, about what materials and application rate tests were undertaken and who did them, clearly showed that the RCAs relied very much on the contractors' quality assurance systems, and carried out very little independent testing. The responses indicated the following:

- No testing – 16 (48%) of the RCAs
- Quality assurance systems – 11 (33%) of the RCAs
- Plate or application rate tests – 6 (18%) of the RCAs
- Visual assessment – 4 (12%) of the RCAs
- Retroreflectivity tests – 1 (3%) of the RCAs.

Most authorities did not review the contractor's quality assurance records to verify the materials being applied and their application rates. In general, the RCAs relied on the life of the markings to assess contractors' performance.

Road marking after reseals

Most RCAs indicated that the installation of road marking after reseals was part of the reseal contract. Responses were:

- Subcontract or requirement under the reseal contract – 20 (61%) of the RCAs
- Road marker nominated to undertake remarking after reseals – 9 (27%) of the RCAs
- Part of overall maintenance contract – 4 (12%) of the RCAs.

Maintenance activities other than remarking

Maintenance activities (other than remarking) undertaken for road markings were:

- sweeping, vegetation control and removal of moss (as activities that would get undertaken if required before remarking) – 18 (55%) of the RCAs.

Fifteen (45%) of the RCAs undertake no additional maintenance for road marking.

Removing unwanted markings

A variety of methods were used by the RCAs for removing unwanted markings. Many used more than one method. The methods were:

- Sand or abrasion blasting (generally used when there is sufficient work to warrant a contract. Reasonably effective, but can damage surface) – 19 (58%) of the RCAs
- Blacking out (used for small amounts and not always very effective) – 15 (45%)
- Water blasting (similar comments to sand/abrasion blasting) – 14 (42%)
- Bitumen emulsion/grit – 2 (6%).

It was acknowledged that resurfacing is a more effective way to remove unwanted markings.

The field surveyors noted some confusing and some unsafe results from the removal of markings. Examples are shown in the photographs that follow.



Confusing 'blacked out' right turn arrow.



Unsafe delineation from 'blacked out' unwanted centre and edge lines. Glass bead was clearly evident on the blacked out markings. Tests showed these lines had higher reflectivity than the new white lines and would therefore be more visible at night (reflectivity readings of 111 and 64 on the blacked out lines, compared with 58 to 80 on the new white lines).

4.14 Traffic management requirements

The RCAs used the following traffic management requirements in road marking contracts:

- TNZ *Code of practice for temporary traffic management* (CoPTTM) – 13 (39%) of the RCAs
- CoPTTM with local amendments – 6 (18%)
- TNZ G/1 *Temporary traffic control* – 13 (39%) of the RCAs. 5 of these advised that they are changing, or will change, to CoPTTM.
- Council specification (specifies TNZ *Working on the road* handbook) – 1 of the RCAs (3%).

4.15 Rating of contractors' performance and traffic management

RCAs were asked to rate their contractors' general performance and traffic management, on a 5-point scale. Some RCAs gave intermediate point ratings. The responses were as follows:

General performance

- Excellent – 4 (13%) of the RCAs
- Good to Excellent – 2 (6%)
- Good – 12 (39%)
- Acceptable to Good – 5 (16%)
- Poor or Very poor – 0 (0%).

Traffic management

- Excellent – 2 (6%) of the RCAs
- Good to Excellent – 0 (0%)
- Good – 18 (56%)
- Acceptable to Good – 4 (13%)
- Poor or Very poor – 0 (0%).

Two RCAs considered it too soon to rate their contractors' general performance and one their contractor's traffic management.

All RCAs rated their contractor's performance as *acceptable or better*.

5 Results of the field surveys

5.1 Survey sample

In total, 643 lines were surveyed, at 211 sites (126 urban, 95 rural) in the 33 RCAs. The surveyors measured line widths and day and night-time visibility.

For the purposes of this survey, assessments were made against the criteria in TNZ P/20 *Performance-based specification for roadmarking*. These performance criteria were not contractual requirements in most cases.

- Line width tolerances were taken as +10%, –5%.
- The daytime visibility criteria used was that the markings should be readily visible for a forward distance of 150 m or, if less than 150 m, as far forward as possible until obstructed by the geometry.
- Night-time visibility was assessed from retroreflectivity measurements. TNZ P/20 specifies that retroreflectivity should exceed $100 \text{ mcd} \cdot \text{m}^{-2} \cdot \text{lux}^{-1}$, measured with a Mirolux 12 reflectometer. This is equivalent to $72 \text{ mcd} \cdot \text{m}^{-2} \cdot \text{lux}^{-1}$ using 30 metre geometry readings with the MX30 retroreflectometer. In accordance with industry practice, 70% of this value was used for yellow no passing lines (ie, $50 \text{ mcd} \cdot \text{m}^{-2} \cdot \text{lux}^{-1}$ for the 30 metre geometry MX30 readings). The field measurements taken were all 30 metre geometry readings using an MX30 retroreflectometer. The readings were not converted to equivalent Mirolux 12 readings, but were compared against the above 30 metre MX30 equivalent readings.

Overall results, by RCA, are shown in Appendix 1.

The total numbers of sites, lines measured and retroreflectivity measurements for the survey were:

- 221 sites – 126 urban and 95 rural
- 643 lines
 - 239 centre lines (172 on straights, 26 on bends and 41 flush medians)
 - 251 edge lines (218 on straights, 17 on the inside of bends, 16 on the outside of bends)
 - 57 no passing (no overtaking) lines
 - 96 other lines, including 29 limit lines and a variety of miscellaneous line types, such as parking or bus stop markings
- 613 line widths, measured and compared with stated standards or expected width
- Daytime visibility assessed for 557 lines
- 808 reflectivity measurements (each being the average of three to seven MX30 readings on a line). These exceed the number of lines because reflectivity readings were taken in two directions on some centre and no passing lines.

5.2 Line widths

- 73% of the 613 line widths measured were within the tolerance of -5% to $+10\%$ of the expected or standard width for that line type.
- 15% (95 lines) were wider than the 10% upper tolerance limit.
- 12% (73 lines) were narrower than the -5% lower tolerance limit.

5.3 Daytime visibility

- 99% (551 lines) of the 557 lines were assessed as meeting the 150 m forward visibility criteria.

5.4 Night-time visibility

The following table shows the number, and percentage, of various line types that had reflectivity measurements below the performance measure, 100% to 200% of the performance measure, or over 200% of the performance measure. Measurements were taken on all lines to enable a measured assessment of the night-time visibility, even though many of the lines were not reflectorised and night-time visibility requirements were not specified in the road marking contract.

The field measurements taken were all 30 metre geometry readings using an MX30 retroreflector. The readings were not converted to equivalent common base or Mirolux 12 readings. They were compared against a performance measure of 72 mcd $\cdot \text{m}^{-2} \cdot \text{luxe}^{-1}$ (50 mcd $\cdot \text{m}^{-2} \cdot \text{luxe}^{-1}$ for yellow no passing lines) for the 30 metre MX30 readings, which is equivalent to the TNZ P/20 specification of 100 mcd $\cdot \text{m}^{-2} \cdot \text{luxe}^{-1}$ measured with a Mirolux 12 reflectometer. This performance measure was not a contractual requirement in most cases.

The table shows the following:

- 45% of all the measurements were at or above the TNZ P/20 performance measure. More of the urban lines had measurements at or above the performance measure than rural lines (49% compared with 40%).
- For sites in areas where the TNZ P/20 performance measures were contractual requirements, 68% of the 166 measurements were at or above the performance measure. These sites were from Auckland City, Southland District and the four TNZ regions.
- 67% of the 493 measurements on lines recorded or specified as reflectorised were at or above the performance measure.
- Only 16 measurements were on thermoplastic lines and 14 (or 88%) of these exceeded the performance measure. One site had two measurements below the performance measure but it was noted that the thermoplastic paint was very worn and the readings may have been from previous paint markings.
- 58% of the 86 measurements on no passing lines were at or above the performance measure. MOTSAM specifically requires no passing lines to be reflectorised.

- 76% of the 30 measurements on limit lines were at or above the performance measure. MOTSAM specifically requires limit lines to be reflectorised.
- More of the measurements on lines on smooth surfaces were at or above the performance measure than measurements on lines on chip seal surfaces (75% of 102 measurements, compared with 41% of 705 measurements). Nearly 50% of the measurements on smooth surfaces were over 200% of the performance measure.

30 metre geometry MX30 measurements							
Line type	Total	Below performance measure		100% to 200% of performance measure		Over 200% of performance measure	
		No.	%	No.	%	No.	%
All (urban and rural)	808	443	55%	197	24%	168	21%
All urban	436	221	51%	109	25%	106	24%
All rural	372	222	60%	88	23%	62	17%
Sites in areas with TNZ P/20 specification	166	53	32%	45	27%	68	41%
Reflectorised – all	493	163	33%	172	35%	158	32%
All thermoplastic lines	16	2	12%	11	69%	3	19%
No passing – all	86	36	42%	31	36%	19	22%
No passing – urban	30	12	40%	9	30%	9	30%
No passing – rural	56	24	43%	22	39%	10	18%
Limit lines – all	30	7	23%	7	23%	16	53%
All lines on smooth surface	102	26	25%	26	25%	50	49%
All lines on chip seal surface	705	417	59%	170	24%	118	17%

Directional issue

The field surveys demonstrated variations in the reflectivity of the lines according to the direction the markings were applied. Road markings should be applied in the direction of travel for the lane to which the marking applies. This is because the paint and reflective beads have better coverage on the face of the aggregate in the direction of travel than on the opposite face. Dual gun systems can overcome the directional issue for applying the paint and the reflective beads.

Measurements were taken in both directions on 122 of the reflective lines surveyed. Most of these were centre lines (84) or no passing lines (27). The measurements were assessed to demonstrate this issue and are not intended to imply that the markings were

incorrectly applied. In many cases, the higher reflectivity readings were in the direction of travel for the lane to which the marking applied.

Analysis of the measurements for these lines shows the following:

- The largest difference between directional measurements on any one line was 119 mcd.
- 16 lines (13%) had measurements above the performance measure in one direction but below in the other.
- 7 lines (6%) had measurements that were lower in one direction than the other by 50% or more.
- 36 lines (30%) had measurements that were lower in one direction than the other by between 25% and 50%.
- 48 lines (39%) had measurements that were lower in one direction than the other by between 10% and 25%.
- 31 lines (25%) had measurements with less than 10% difference between one direction and the other.

5.5 Observations

In addition to the specific site inspections, the surveyors made general observations of road markings on the routes driven between the sites.

Their observations included the following:

- The daytime appearance of markings was generally good and there were very few examples of unexpected, non-standard or misleading markings.
- Some blacking out of markings was not effective. Old markings showing through can be misleading and potentially unsafe.
- No problems with the reinstatement of markings after reseals were observed. However, there were rural routes with quite significant lengths of centre or edge lines missing due to dig-out repairs.
- Remarking using non-reflectorised paint over thermoplastic resulted in a lower reflectivity or level of service. The reflectivity was reduced even though the line may have appeared whiter in the daytime.
- There was some variation in the marking of edge line tapers at urban intersections. Some RCAs had a simple, straight edge line taper from the kerb; others continued the edge line around the kerb radius at the intersection. The latter appeared unnecessary and could add costs to the remarking.

6 Discussion

6.1 General

- The survey showed that the overall daytime performance and standard of road markings was good. Some RCAs had increased the level of performance of their road markings through knowledge, trials and good contractual relationships.
- The wide range of MX30 reflectivity measurements from the field surveys indicates a wide range of night-time visibility performance.
- The interview surveys showed that there is some demand for a guideline on markings for private land areas with public access (car parks etc), to achieve nationwide consistency for these areas. The interview surveys also showed that there is variation in the use and format of lane arrows for tourists.
- There is a strong reliance by RCAs on the expertise and integrity of their road marking contractors. In general, the authorities relied on visual assessments and the amount of remarking needed to assess contractors' performance. The low levels of supervision and checking on road marking may reflect the relatively low expenditure on road marking, compared to other road network budget items.
- All authorities rated their contractors' general performance and their traffic management as acceptable or better. More than half rated their contractors' performance as good or better.
- Most RCAs are using method-based contracts. Only three (apart from the TNZ regions) have TNZ P/20-type performance-based contracts. The TNZ specifications are the guidelines adopted by most RCAs and should be retained, even if they are not in current use by TNZ.
- Trials have shown waterborne paint to be cost effective over the full life cycle. However, survey respondents pointed out that it is subject to climatic conditions during its application.
- The most common factors affecting road markings were gritting for ice, snow, and seal bleeding problems.
- Removal of unwanted markings is a safety issue. It is typically undertaken by blacking out the markings or removing them by abrasion blasting (sand or water blasting). Most authorities stated that relatively small amounts of this work are undertaken. Surveyors observed examples of old markings having been ineffectively removed. The results ranged from confusing indications to misleading and potentially unsafe delineation. Resurfacing is the most effective way to remove unwanted markings.
- Good, clear road markings can enhance road safety. A high level of direct supervision of road marking work is not necessary, as visual inspections can provide a lot of information and quality assurance records can be checked.

6.2 Best practice

A variety of policies, management procedures and specifications are being used for road marking. The field surveys measured performance criteria that were not contractual criteria in many cases. Road marking is not a 'one size fits all' process. It is difficult, therefore, to identify specific policies and practices as constituting 'best practice'. The surveyors, however, consider that elements of best practice include:

- adopting clear policies on what markings to use on which roads, including, as necessary, clarification of any discretionary or optional issues included in any national guidelines that are adopted
- maintaining a good database of road markings
- having procedures to remark the markings that should be on the network (this does not necessarily mean remarking all existing markings)
- having remarking programmes based on assessed needs
- having formal customer service request systems
- developing good, working contractual relationships that allow trials, to increase knowledge and ensure continuous improvement of the performance of road marking
- using reflectorised markings to improve night-time visibility, especially for no passing lines and centre lines
- completing reseals to remove unwanted markings if removal by blacking out or abrasion blasting could result in unsafe delineation
- supervision of road marking contracts using industry-developed guidelines and drawing on quality assurance records.

The degree to which these elements are adopted depends on the road marking budget and the RCA determining that they will obtain value for the likely costs.

7 Recommendations

- RCAs should continue to work with their road marking contractors to apply best practice and to undertake trials to increase knowledge and ensure continuous improvement in the level of service from road markings.
- The requirements for reflectorised markings should be reviewed. More use of reflectorised markings could improve night-time safety.
- The removal of unwanted markings by blacking out or abrasion blasting should be limited to small amounts of this work and locations where ineffective removal will not create a safety problem. Resealing should be used for large amounts of this work or where safety problems could be created.
- The LTSA should, through its Standards and Guidelines Steering Group, promote the development of guidelines for road marking on private land areas that have public access and road-type use.
- RCAs should assess whether they can achieve better value from remarking programmes based on an assessment of needs, rather than simply carrying out time-based remarking of all existing markings.
- The NZRF should continue to promote best practice and develop guidelines to assist RCAs to get the best value from their road marking programmes.

Appendix 1: Summary of field surveys, by RCA

RCA	No. of sites (U = urban R = rural)	No. of lines	Width		Day visibility		Night visibility			
			No. within tolerance	No. not within tolerance	No. meeting criteria	No. not meeting criteria	Min. MX30 measurement	Max. MX30 measurement	No. over performance measure	No. below performance measure
Far North District	3U, 5R	26	15	9	25	0	9	325	17	17
Whangarei District	5U, 2R	23	13	8	23	0	18	342	10	16
North Shore District	5U, 0R	13	9	4	12	0	27	393	14	5
Auckland City	5U, 0R	16	9	7	16	0	19	262	11	6
Manukau District	5U, 2R	16	11	2	9	0	22	269	21	3
Hauaraki District	4U, 4R	25	18	6	22	0	20	209	21	14
Hamilton City	6U, 0R	21	18	1	12	3	27	317	20	6
Otorohanga District	3U, 4R	16	12	2	8	0	25	178	2	15
Waitomo District	4U, 3R	19	11	1	6	0	25	362	11	10
Rotorua District	4U, 4R	23	19	4	19	0	25	237	14	19
TNZ Hamilton	4U, 4R	27	15	12	18	0	34	368	29	4
Gisborne District	3U, 2R	22	12	10	22	0	14	299	18	12
Wairoa District	4U, 3R	18	5	13	18	0	19	292	19	7
Stratford District	2U, 2R	12	6	6	11	0	37	74	3	11
Ruapehu District	3U, 3R	16	9	7	14	0	27	67	0	20
Manawatu District	3U, 3R	16	11	5	14	0	13	217	5	15
Wellington City	7U, 0R	19	13	5	14	0	25	223	5	14
Masterton District	4U, 3R	22	18	4	20	0	21	110	3	20
Carterton District	4U, 4R	16	15	1	14	0	24	116	5	14
Kaikoura District	0U, 0R	0	No field surveys in Kaikoura							
TNZ Wanganui	2U, 5R	29	15	14	25	0	23	242	26	14
TNZ Wellington	2U, 3R	15	13	1	12	0	19	306	6	11
Hurunui District	2U, 4R	18	15	2	18	0	16	141	4	15
Waimakariri District	3U, 3R	21	16	5	21	0	15	232	12	16
Christchurch City	9U, 0R	21	14	7	21	0	32	251	9	17
Banks Penin. District	2U, 3R	9	9	0	9	0	16	53	0	10
Selwyn District	3U, 5R	21	18	3	19	0	16	66	0	29
Ashburton District	4U, 4R	23	19	4	23	0	27	249	6	20
Timaru City	4U, 4R	25	23	0	22	0	8	473	17	16
Waitaki District	6U, 3R	21	18	1	16	0	14	105	3	23
Clutha District	4U, 4R	23	16	7	20	2	21	178	12	16
Southland District	3U, 4R	22	9	11	20	0	24	245	16	15
TNZ Dunedin	4U, 5R	29	21	6	29	0	41	292	28	10
Totals	126U, 95R	643	445	168	552	5	8	473	367	440

Note

For the purposes of this survey, assessments were made against the criteria in TNZ P/20 *Performance-based specification for roadmarking*. These performance criteria were not contractual requirements in most cases.

- Line width tolerances were taken as +10%, –5%.
- The daytime visibility criteria used was that the markings should be readily visible for a forward distance of 150 m or, if less than 150m, for as far forward as possible until obstructed by the geometry.
- Night-time visibility was assessed from retroreflectivity measurements. TNZ P/20 specifies that retroreflectivity should exceed $100 \text{ mcd} \cdot \text{m}^{-2} \cdot \text{lux}^{-1}$, measured with a Mirolux 12 reflectometer. This is equivalent to $72 \text{ mcd} \cdot \text{m}^{-2} \cdot \text{lux}^{-1}$ using an MX30 retroreflectometer. The value for yellow no passing lines was set at 70% of this (ie, $50 \text{ mcd} \cdot \text{m}^{-2} \cdot \text{lux}^{-1}$ for MX30 readings).

Appendix 2: Survey of road markings – Questionnaire

Road controlling authority: _____

Person(s) replying to questionnaire: _____

Position in organisation: _____

Contact phone number: _____

Contact email: _____

Interviewer: _____ Date: _____

Road network and road marking policies	Prompts
1. What length of sealed road do you have? Urban chip seal km smooth surface km other km Rural chip seal km smooth surface km other km	'Smooth surface' covers asphalt, slurry, friction course etc. 'Other' covers paving etc.
2. Do you have any special conditions that may affect your road markings and, if so, how do you manage these special conditions?	Snow, gritting.
3. Do you have delegated authority for road markings on any other RCA roads or section(s) of state highway or another RCA's roads? Yes / No If 'Yes', please define which sections/roads:	Define SH and RP range or area.
4. What standards do you use to determine what road marking is required? MOTSAM Yes / No RTS 5 Yes / No Other	
5. What lengths or proportion of your network have the following markings and what criteria do you use to determine where to use these markings? <u>km</u> or <u>%</u> <u>criteria</u> centre line only edge line only edge and centre line	Criteria could include traffic volume, road type and may vary depending on edge marker delineation.

6. What is your policy on line width for: edge lines centre lines other?			Traffic volume. Road type.
7. Complete the table below to show if you use any local standards or variations from MOTSAM for the road markings listed:			
Road marking	Yes / No	Comment (Briefly describe standard and/or situation it is used in and any evaluations undertaken)	Attach copies of local standards or variations if necessary.
Flush medians			Continuous across intersections.
Painting of kerbs on traffic islands			What is your policy?
Urban right-turn bays			MOTSAM full with chevron diverge (Fig. 3.26) or shorter with continuity line diverge (Fig 3.27).
Intersections with public access to private land			Who controls markings at accesses to service stations, supermarket car parks etc?
Public access private land			Car parks.
Centre lines and limit lines at pedestrian crossings			
Arrows for tourists			Directional arrows on road at exits from rest areas etc.
KEEP CLEAR wording c.f. cross-hatched clear zone			

Alberta markings at roundabouts			
Other (describe)			List any other markings not included above.
8. What procedures or investigations have you used to influence or change your road marking design and/or frequency of marking ?			Crash studies, project or existing road safety audits.
9. Have you reviewed your no passing lane markings as a result of the LTSA survey in 2000 or as a result of reading RSS 13? Yes / No			
10. What specifications do you use for road marking materials? TNZ M/7 Yes / No TNZ M20 Yes / No Other			
11. Which markings and on which roads do you specify the use of reflectorised materials for?			Centre lines, edge lines, limit lines, arrows, other.
12. Do you assess wet night visibility of your road markings? Yes / No If 'Yes', what programme do you have for this?			
13. Do you carry out tests to determine the skid resistance of your markings? Yes / No If 'Yes', what programme do you have for this?			
14. What policies do you have to select different material types (eg, chlorinated rubber modified alkyd, waterborne, thermoplastic)?			
15. List the product type and amount of any long-life markings you have on your network:			Thermoplastic, cold applied plastic. Km, m, sq m.
16. Are there opportunities for materials trials on your network? Yes / No			Profiled edge lines, other.
17. Describe any trials and evaluations that have been or are being undertaken:			Profiled edge lines.

18. How do you control the standards and specifications for road markings in new subdivisions? Describe any problems you have had with developers installing non-standard markings, and how you have rectified these.	
19. What form of inventory or database of road markings do you maintain?	Industry concerns. RAMM is not adequate and issue under consideration.
20. What procedures do you have to update your inventory or database of road markings?	
21. What process do you have for handling public enquiries/complaints/requests?	
22. How are these actioned or authorised for action by your contractor?	

Contract management procedures	
23. Who manages your road marking contract programme?	Asset manager, professional service consultant, TNZ consultant manager
24. What QA or quality control requirements are included in your contract?	
25. What is the contract term?	

26. Circle or tick one of the options below to show when the current contract was let: ☐ < 3 months ago ☐ 3 to 6 months ago ☐ > 6 months ago	
27. Is your contract method-based or performance-based?	
28. If it is performance-based, what are the performance criteria?	Day and night-time colour and visibility, skid resistance, durability.
29. If method-based, what are the materials application rates?	Paint dry film thickness. Bead drop-on rates, etc.
30. What specification do you use? TNZ P/12 or P/22 Yes / No What version? TNZ P/20 Yes / No Other (state)	
31. Is the contract a stand-alone contract or is road marking a sub-contract activity?	
32. What is the relationship that you have with your contractor?	Partnering, service agreement.
33. Have you recently changed or investigated a change in the way you manage your road marking work? What was the outcome?	
34. Is your remarking programme time based? Yes / No If 'Yes', state the period(s) between markings, noting any differences for different classes of road or high wear locations. If 'No', please state how your programme is determined.	

35. What tests do you do to check the standard of materials and application rates?	
36. Who carries out these tests, and at what intervals?	
37. What procedures do you have to control the installation of road markings after resealing?	
38. What maintenance, other than remarking, do you undertake for road markings (eg, sweeping, vegetation control)?	
39. What procedures or specifications do you have for removing unwanted markings? How well do they work?	
40. How well does your contractor perform? (Assess on a scale of 1 to 5.)	Scale: 1 = very poor 3 = acceptable 5 = excellent
41. What guidelines do you require your contractor to conform to, in managing traffic control?	
42. How well does your contractor manage traffic control? (Assess on a scale of 1 to 5.)	Scale: 1 = very poor 3 = acceptable 5 = excellent
General	
43. Any general comments or suggestions on how the LTSA could assist you with any problems that cause you concern with respect to road markings?	

Road safety survey series

RSS 1	<i>Traffic signal light output</i>	1995/96
RSS 2	<i>Street lighting</i>	1995/96
RSS 3	<i>Treatment of slip lanes at traffic signals</i>	1995/96
RSS 4	<i>Stop and give way controls at intersections</i>	1996/97
RSS 5	<i>Advisory speed signs</i>	1996/97
RSS 6	<i>Pedestrian crossings</i>	1996/97
RSS 7	<i>Temporary speed limits</i>	1998
RSS 8	<i>Traffic control at road works</i>	1998
RSS 9	<i>Safety management systems</i>	1998
RSS 10	<i>Skid resistance</i>	1999
RSS 11	<i>Pedestrian platforms</i>	1999
RSS 12	<i>Floodlighting pedestrian crossings</i>	1999
RSS 13	<i>No passing lines</i>	2000
RSS 14	<i>Roundabouts</i>	2000
RSS 15	<i>Roadside hazard management</i>	2001
RSS 16	<i>Road hierarchies</i>	2001
RSS 17	<i>School crossing facilities</i>	2002
RSS 18	<i>Data collection</i>	2002
RSS 19	<i>Traffic signs</i>	2003
RSS 20	<i>Vehicle entrances, stock crossing facilities and amenity carriageway surfacings</i>	2004
RSS 21	<i>Traffic calming</i>	2004
RSS 22	<i>Road markings</i>	2004

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LASERLUX®:

AUTOMATED REAL TIME PAVEMENT MARKING RETROREFLECTIVITY MEASUREMENTS

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ABSTRACT

Laserlux, an automated real time mobile retroreflectometer is being used to measure the retroreflectivity of pavement lane markings. This vehicle-mounted retroreflectometer provides the measurements needed for proper highway pavement marking management. Quick, simple, reliable, objective, and inexpensive measurements at highway speed are the key to getting a statistically representative sample, without hindering the flow of traffic, nor putting the human operators at undue risk. The Laserlux retroreflectometer has repeatability within a tolerance of 10% as measured under supervised testing by the FHWA. The system can be used for various applications, such as implementing pavement standards, planning re-striping strategies, measuring performance of different materials application methods, holding contractors accountable, and establishing a pavement marking management data base.

KEYWORDS

Retroreflectivity, Pavement markings, Stripe measurement, Night visibility, Striping.

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1. INTRODUCTION

1.1 Pavement Markings

Pavement lane markings (stripes) are an invaluable mechanism to facilitate the guidance of vehicles along the highways of the nation. They bring comfort to drivers who know that these markings can be relied on to keep them from driving off the road, to indicate when passing maneuvers may be safe, and to keep vehicles in organized

queues under multilane conditions. Pavement markings are so valuable that virtually any road with significant traffic is marked, and driving on roads that are not marked or poorly marked, results in more driver stress and fatigue, and potentially more vehicular mishaps. According to the Manual on Uniform Traffic Control Devices (1), markings have definite and important functions to perform in a proper scheme of traffic control. Section 3A-2 of the MUTCD states "Before any new highway, surfaced detour, or temporary route is opened to traffic, all necessary markings must be in place."

Millar (1) indicates that pavement markings reduce crashes by 21% and improve traffic flow, and concludes that on average every \$1 spent on pavement striping yields \$60 in benefits, with returns of up to \$103 on some classes of roads.

During daylight hours and under dry pavement conditions almost any type of marking would suffice. Under good ambient light conditions, simple painted lines would be adequate, reflecting and scattering light in every direction, so as to be visible from all angles. After dark however, the situation changes. Typically, the only source of lighting is directional, emanating from the headlamps of the vehicle travelling down the highway. In the case of simple painted lines, this light would then typically reflect off the pavement marking paint, in the direction of travel, not back to the vehicle where it can be seen by the operator. Consequently, painted markers may be difficult if not impossible to see at night, and are typically not used. Gu and Hubert (3) cite U.S. Department of Transport statistics showing that 56% of traffic fatalities occur at night, even though there is much greater traffic density during the day. According to the Traffic Control Devices Handbook (1), pavement markings must define the path of safe travel and must be clearly visible in daylight, in darkness and periods of adverse weather, such as rain or fog.

Highway administrators and engineers have improved this by embedding glass beads in the pavement markings, so the directional light from the headlamps is retro-reflected, with much of the light energy being retro-reflected back in the direction of the approaching vehicle (Figure 1). This solves the problem of poor night visibility, and even reduces the problem of poor visibility under wet conditions, providing of course that the film of water covering the road is not thick enough to cover and obscure the beads. Consequently, striped roads with properly emplaced beads offer a tremendous improvement in nighttime, and some improvement under wet weather conditions.

Unfortunately, pavement markings deteriorate with time. Ultraviolet light and heat from the sun can deteriorate the binder, releasing the beads. Abrasion from traffic, snowplows, and sand can wear off the beads. The action of chemicals (primarily road salt) can result in significant deterioration. Ultimately, all or most of the beads will disappear, and the beneficial effect of the beads is also gone. Ultimately, each road must be re-striped. The decision of where and when to re-stripe has in the past been rather arbitrary and unscientific in the absence of reliable data.

1.2 Measurement of Pavement Markings

The science of measuring pavement markings is relatively young. Portable hand-held units have had mixed success in the past. Gu and Hubert, (3) give reviews of various handheld units. These measurements were in the past better than no measurements, but the measurements were highly variable. There was typically poor correlation between measurements made by different units, because of different geometries or different hardware implementations. It was also difficult to get reproducibility, because of the typically high spatial variability of the pavement stripe.

Today, the inadequacies of handheld units are obvious. They are too slow and cumbersome to acquire the large number of samples required, and their use puts the operators of the units at undue risk from traffic

Handheld units operate in a static mode. Consequently they are severely limited in the number of measurements that can be made. Typically, the units must be positioned, the measurement taken, and then recorded. Even with digital data logging equipment, manual measurements are limited and require a full time operator and result in only 500-1000 measurements per man-shift. This is certainly not cost effective, and provides a sample that is far too small for large road networks.

In addition, the use of handheld units requires that the road/lane being measured be closed to traffic. In many jurisdictions this is unthinkable. Equally unthinkable is the prospect of putting the operator of handheld equipment at risk by making measurements without closing the road/lane to traffic.

More recently, measuring units using laser light rather than incandescent sources have been used. An Ontario Ministry of Transportation study indicated that there was a very good correlation between the two light sources (3).

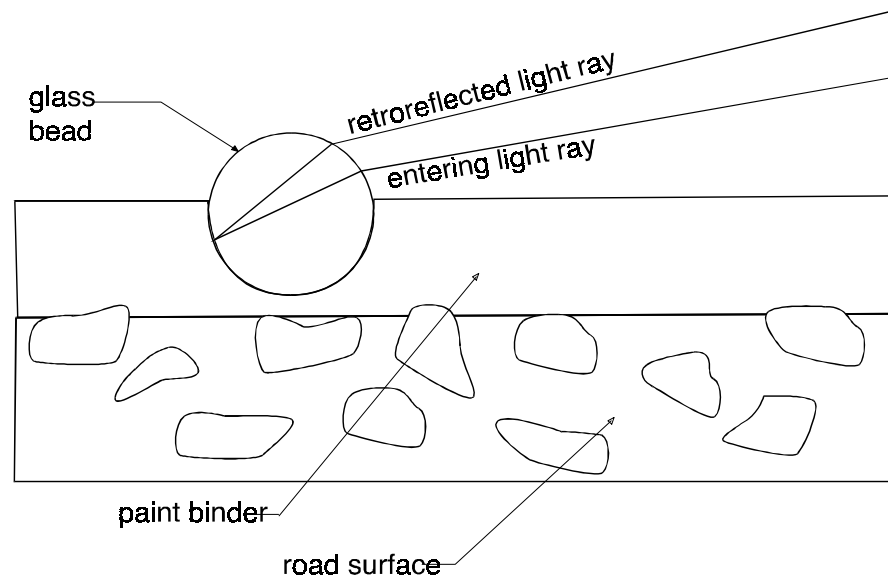


Figure 1. Geometry of retroreflectivity. Light ray enters the glass bead, gets refracted, travels through the bead, and gets internally reflected off the rear of the bead, and exits the glass bead and gets refracted back into the general direction of the incoming light ray.



Figure 2. Picture of a Laserlux unit mounted on the side of a Roadware data acquisition platform.

1.3 Laserlux

Laserlux, a real time scanning retroreflectometer (Figures. 2-4) was developed for the purpose of providing simple, reliable, objective, and inexpensive high speed marking surveys, needed for the management of highway infrastructure.

The Laserlux hardware is typically installed in a van that can be driven at highway speeds while collecting data at a rate of up to 32,000 measurements per hour. The system utilizes a laser beam, and consequently can be used under all ambient light conditions, from bright sunlight to total darkness. The unit uses 1/3 scaled geometry using either standard North American or European (CEN) geometry.

The Laserlux software[®], uses the QNX[®] real time operating system to facilitate approximately 9 stripe measurements per second, consisting of 200 sampling points for each measurement, with an incoming data frequency of approximately 100 MHz during each measurement. In real time, (9 times per second) the Laserlux software identifies the stripe within a 1.07 m scan width, calculates the peak retroreflectivity, displays it to the user console, and retains the retroreflectivity measurement. Over the distance of a user selected station interval, the mean retroreflectivity is reported, as well as the variability. The user video console display can be superimposed on a video image of the actual stripe being measured (Figure 5). Optionally, event codes for different conditions can be entered by keyboard, and become part of the record.

In terms of productivity, the Laserlux unit is up to 400 times as efficient as a handheld unit.

2. LASERLUX HARDWARE

2.1 Principle

The Laserlux retroreflectometer was developed by Potters Industries Inc., who hold the patent for this unit. The unit uses the principle of a scanning laser to deliver a beam of coherent light to the pavement stripe. The laser light is retroreflected back to the unit (Figures 3, 4), where it is detected by an optical detector. Units of measurement are millicandella per meter squared per lux ($\text{mcd}/\text{m}^2/\text{lx}$).

The Laserlux unit is designed to use a 1/3 scaled geometry, measuring the pavement markings at a distance of 10 m (Figure 4). The co-entrance angle can be set at either the Old North American Standard of 1.5° (4), or the European Committee for Normalization angle of 1.24° (5). The observation angle is fixed at 1° .

The window of measurement on the pavement covers an area of approximately 1.07 m wide by 0.20 m deep.

2.2 Laser Path

The Laserlux unit utilizes a 10 milliwatt 632 nm coherent light source to measure retroreflectivity. The beam is transmitted or reflected through a series of lenses and mirrors (Figure 6), including a double sided rotating mirror, which acts to “sweep” the beam across the forward field of view at a rate of about 9 rotations per second.

Whatever portion of the beam is retroreflected from the pavement markings, (and typically a very small amount of direct reflection off pavement components) returns to the Laserlux unit, and is again transmitted or reflected through a series of lenses, filters and mirrors, including the back of the rotating mirror.

Synchronization of the outgoing beam and the return beam is facilitated by the simultaneous use of both sides of the rotating mirror. The mirror also triggers a hardware interrupt to indicate the beginning of the active sweep.

The return beam moves through a series of interference filters, used to reject ambient light, and is measured by an optical detector. The signal is then conditioned by a specially designed high gain amplifier, and sent to the central data acquisition computer (CDAC).

2.3 Data Acquisition

The electrical signal is digitized by a 12-bit 100 kHz analog to digital (A/D) converter in the CDAC. This is a continuous process, with each scan consisting of 200 samples being digitized in short 2 millisecond bursts, with approximately 9 scans per second. The initiation of digitizing is triggered by a hardware interrupt from the rotating mirror.

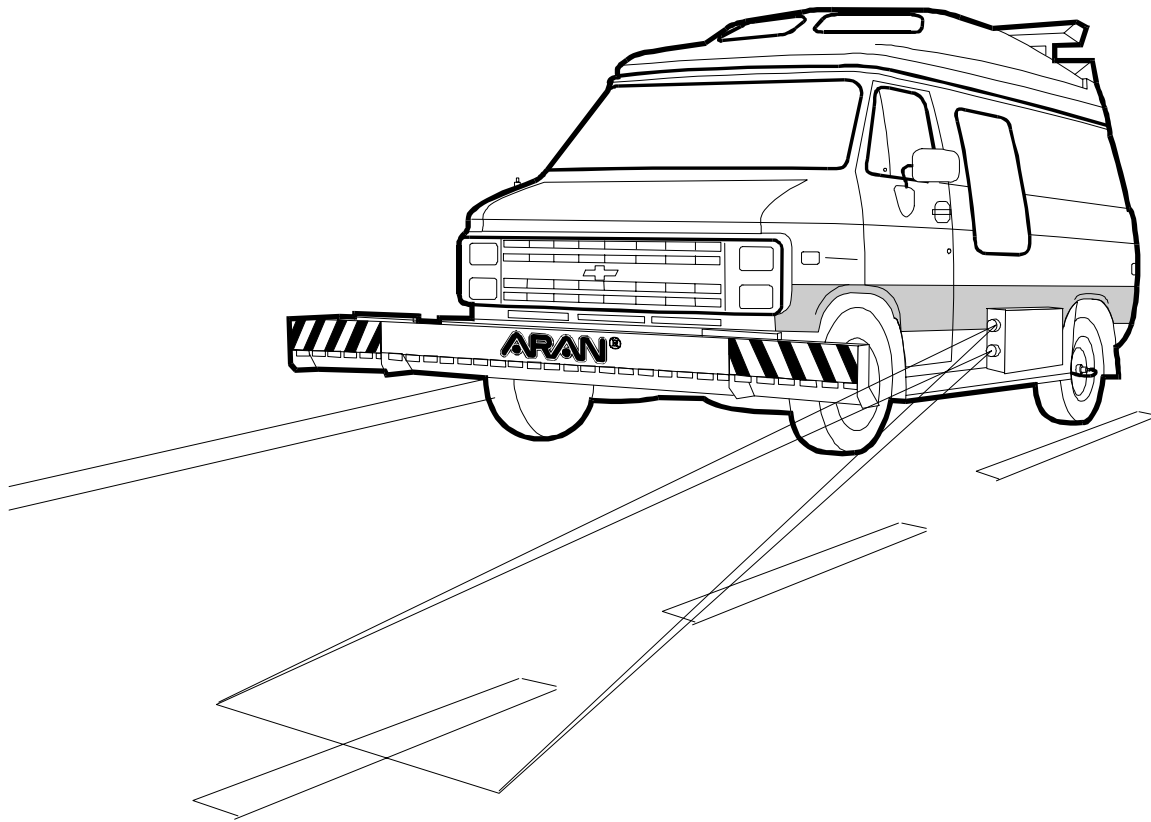


Figure 3. Schematic of the scanning laser path.

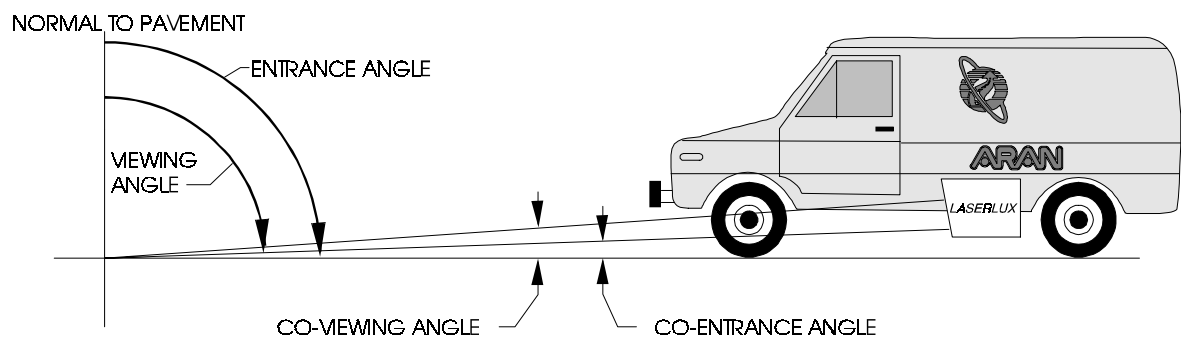


Figure 4. Laserlux geometry. The co-entrance angle can be set at either the Old North American Standard of 1.5° , or the European Committee for Normalization angle of 1.24° (CEN, 1995, ASTM, 1995). The observation angle is fixed at 1° .

The Laserlux unit features digital controls on the mirror rotation, laser, and a tilt motor to adjust the vertical alignment of the unit. It has a feedback signal to indicate the tilt position, and a temperature signal to indicate operating temperature.

The unit also features a distance measuring instrument (DMI) attached to the wheels of the vehicle. This DMI unit provides electrical pulses to the CDAC, correlating to distance traveled. A timer/counter card in the CDAC accumulates distance traveled (chainage) in the form of a cumulative tick count.

2.4 Video

The Laserlux unit has video camera incorporated into the unit, which images the exact part of the roadway being scanned by the laser. In conjunction with a dash-mounted monitor, the video camera is normally used to aim the Laserlux unit, and can be used by the driver for vehicle guidance in terms of centering on the stripe.

Alternatively the video image can be recorded on video tape during data collection, with the Laserlux data screen superimposed over the image of the stripe, using a video overlay card.

3. LASERLUX SOFTWARE

3.1 Operating System

The Laserlux software[®] is based on the QNX[™] operating system. QNX is a UNIX-like operating system, however, with the additional ability to prioritize tasks. QNX is considered a “real-time” operating system because of its advanced interrupt handling and task prioritization capabilities. This makes it ideal for the complex data handling requirements of the Laserlux system.

The software is coded in the “C” language, and uses a text based interface (Figure 7). This is to reduce computational overhead on the CDAC.

3.2 Data Acquisition

The acquisition of retroreflectivity measurements from the A/D converter to the CDAC is done by the use of an interrupt handler, which has the highest priority of any of the tasks on the system. Consequently, the CDAC is always prepared to handle the stream of 200 data points over a 2 ms timeframe every 1/9 sec. The synchronization of the data stream with the data acquisition system is achieved by the use of a hardware interrupt.

Periodically, the CDAC will call for temperature and retroreflectometer tilt position measurements. These measurements are also handled through the A/D converter. However, they are sequenced so as not to interfere with the primary data acquisition of the retroreflectivity data. If the tilt is out of position, it is corrected by the software in real time using digital control signals.

Periodically, the CDAC will call for chainage measurements. These are available on the accumulator of the timer/counter card.

3.3 Data Reduction

The timing of the reduction of the scan data of 200 sampling points to summary data for each scan takes place using two different methods. For skip lines, the data reduction is done immediately after acquisition. For continuous lines, the data reduction is done only for the last scan during a “sampling interval”, which is typically about 3 m of travel down the highway. The purpose of this methodology is to make the measurement as independent as possible of vehicle speed.

The actual data reduction consists of identifying the peaks in the scan, choosing the one or two most prominent and calculating the average peak retroreflectivity across each stripe. Figure 8 shows a single scan, indicating dual stripes. Each scan is displayed to the CDAC screen (Figure 7) and the peak retroreflectivity is reported below the graph. Scan data is normally discarded after peak retroreflectivity has been calculated, but samples can be recorded by the computer for later review of the retroreflectivity profile.

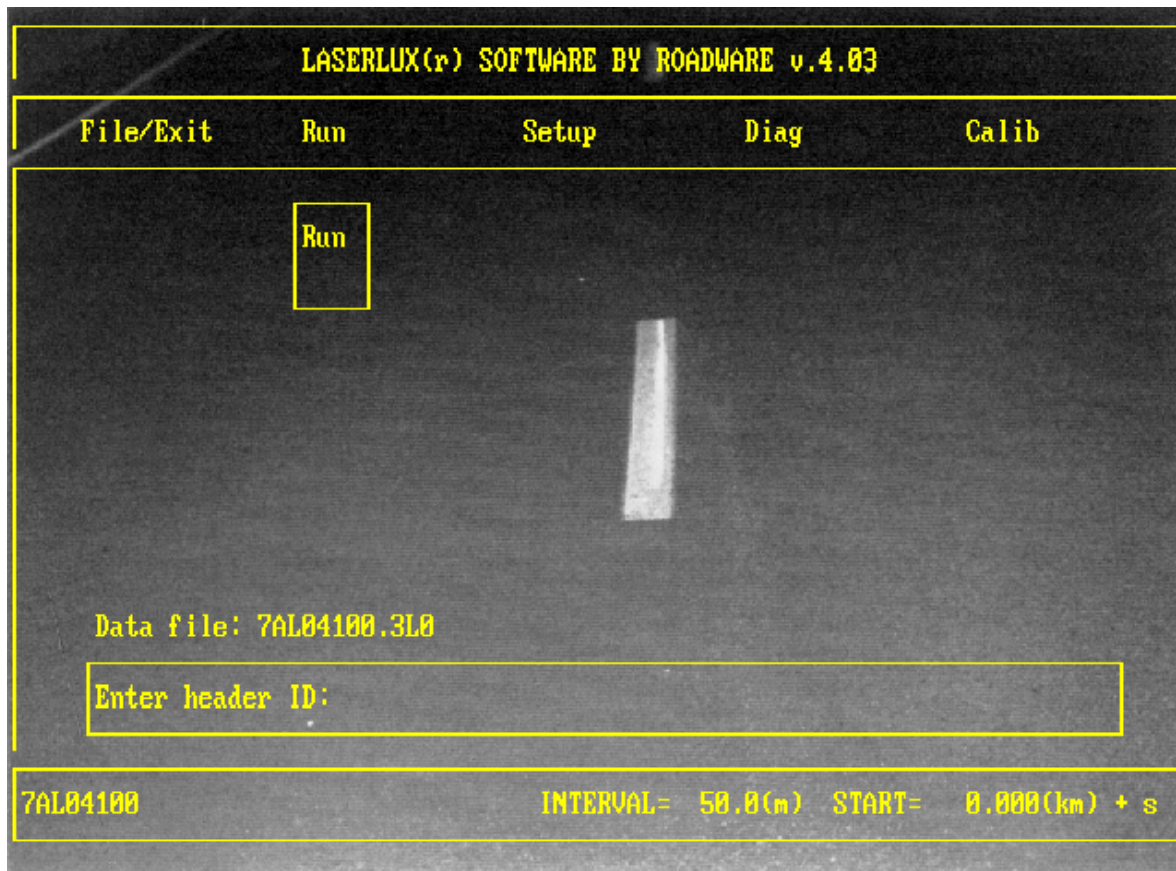


Figure 5. Overlay of the Laserlux console display on the road video.

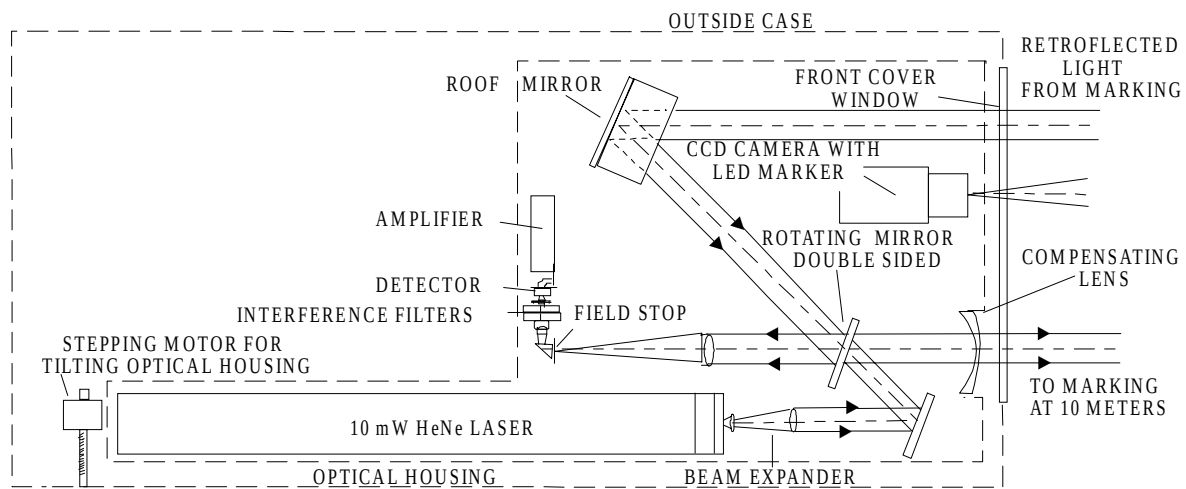


Figure 6. Optical diagram of the Laserlux unit.

3.4 Data Summary

Data is summarized on the basis of operator selected station intervals. All peak retroreflectivity measurements are stored until the end of the station interval, at which time these data are summarized, and the peak retroreflectivity measurements are discarded.

3.5 User Interaction – Event Codes

During the course of data collection, the user interacts with the Laserlux system via the CDAC keyboard. There are two classes of events. The first class is series of events that affect the data collection process:

- Stripe color, (W)hite or (Y)ellow—Software switches between white and yellow calibration factors
- Number of lines, (O)ne or (T)wo—Software switches between single and dual line modes.
- Line type, (S)kip or (C)ontinuous—Software switches between chainage based sampling, and time based sampling with probabilistic correction.
- (L)eft skip—Software assumes left line is skip and right line is continuous if two lines are found.
- (R)ight skip—Software assumes right line is skip and left line is continuous.
- Data Validity (V)alid or (I)nvalid data—Software switches between processing the incoming data and ignoring it.

The second class of events are user defined. These have no affect on the operation of the software, and are used rather for the purpose of clarification of output charts only. Examples of such events could include such things as concrete or asphalt pavement, construction zones where pavement markings may be obscured, bridges, exits, or intersections, where pavement markings may by missed due to driving wander, or the need to avoid traffic.

3.6 Reporting

A report in the form of an ASCII file is made at the end of the run, when data acquisition is shut down. The following items are reported at the end of each station:

- the chainage (distance traveled, in the units specified at the beginning of the run)
- the mean retroreflectance over the last station interval
- the number of valid scans (scans returning appropriate data)
- the number of invalid scans (scans not returning appropriate data)
- the number of dual valid scans (scans returning appropriate data for dual lines)
- the mean retroreflectivity of the right line
- the mean retroreflectivity of the left line
- the mean speed (in km/h or mph) over the station interval
- the mean retroreflectivity of the road pavement
- the event code
- the standard deviation of the average retroreflectivity
- the standard deviation of the average right retroreflectivity
- the standard deviation of the average left retroreflectivity
- the number of invalid scans due to raised pavement markers
- the temperature inside the measurement unit in degrees Celsius

In addition, the overall mean retroreflectivity and standard deviation of all valid measurements over the length of the run are reported.

A graphical plot of the data can be generated from this report (Figure 9).

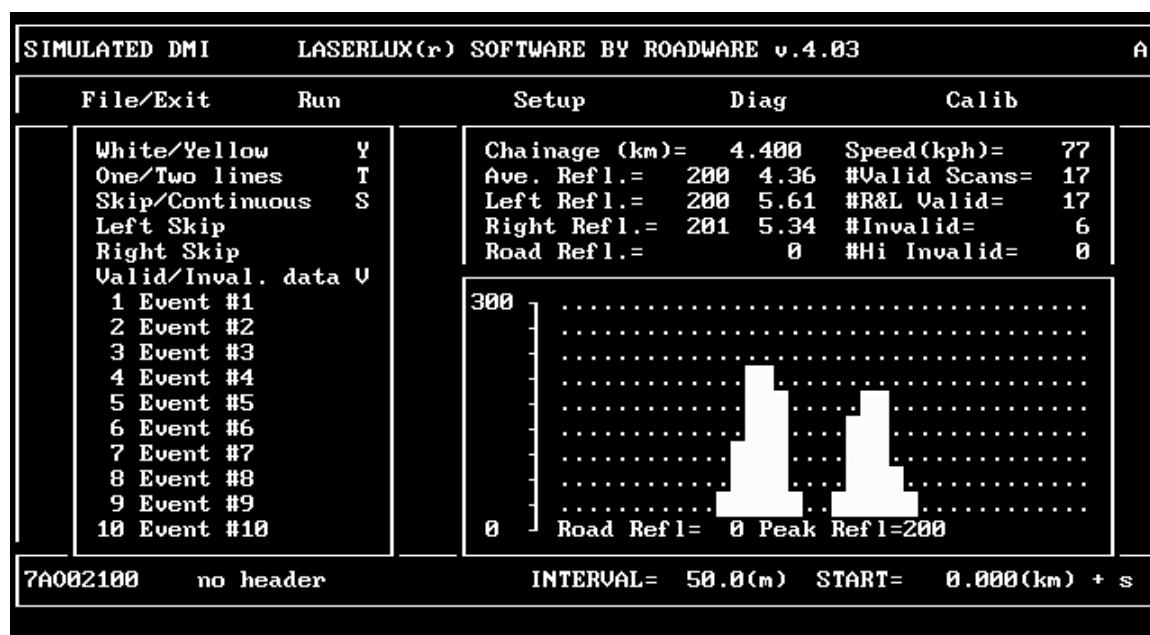


Figure 7. Main runtime Laserlux screen .

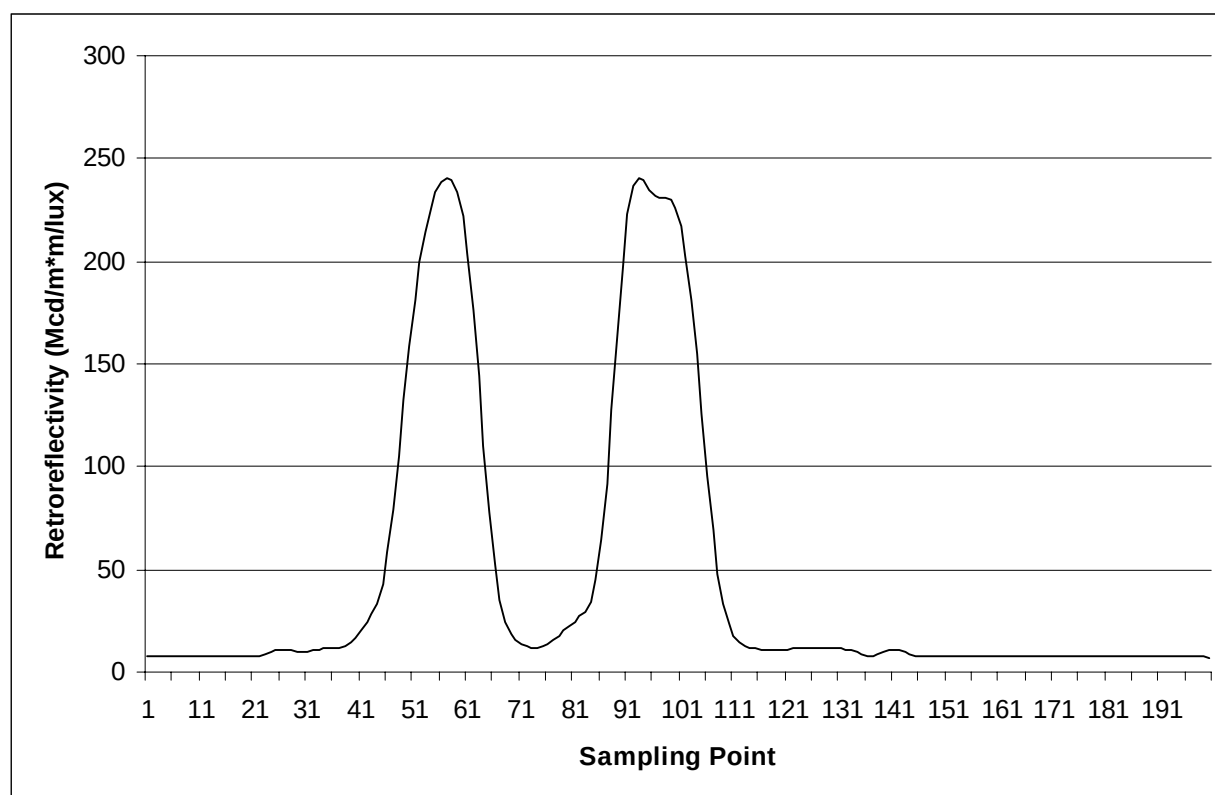


Figure 8. Example of a raw single Laserlux scan across a 1 m section of pavement, showing the retroreflected signal from a double painted stripe, plus reflectance from the road surface, uncorrected for residual ambient light.

4. PERFORMANCE

4.1 Accuracy and Repeatability

Standards of accuracy for measuring retroreflectivity of pavement markings are evolving. Currently, there are no absolute “ground truths” or benchmarks with which to measure retroreflectance. While various manufacturers of handheld and mobile instruments produce repeatable results amongst their own devices, no single traceable standard has been yet established. Laboratory instruments often measure test panels in a manner that cannot be easily duplicated by handheld or mobile devices with complete assurance. Some standardization of methods has been established for handheld instruments by ASTM (7). Not only do different instruments measure the same test panel with different results, but also test panels themselves may vary significantly from one manufacturer to another.

Until such time as a universal standard is available, working standards must be used by agencies seeking to establish performance specifications for pavement marking quality and instruments. These working standards have been established by several states by specifying a particular instrument or test panel as the truth. This is an important issue both to establish safety levels, as well as to monitor performance levels of materials and contractors.

In whatever way these standards, or ground truths, are established, there must be correlation between readings of one manufacturer and another. Laserlux was engineered with a software calibration capability that provides the confidence that markings measured by one model of handheld instrument can be repeated by the mobile instrument. This calibration can be performed in the field as frequently as desired by the operator or as department policy dictates. A test panel, representing the truth, is used to set the Laserlux calibration during the initial setup before a measurement mission. This takes approximately 10 minutes. Separate calibrations can be made for yellow or white markings if desired. The test panel is usually a one meter metal panel which has its retroreflectance value marked on the back and the direction that the measurements must be made. It is important that this panel is measured at regular intervals by the handheld or laboratory instrument to ensure its value remains unchanged due to handling or mechanical damage. It should be as uniform along its linear length as possible to prevent variation. Periodic comparisons with field markings should also be made to be certain the mobile unit continues to correlate with the handheld instrument. Obviously, it is not possible to take most laboratory instruments to the field or take a field marking to the laboratory so a hand held unit is the most realistic method of checking consistency.

The precision required of this type of measurement is up for debate. A 10% error level is commonly talked about in terms of a standard. This type of precision is, however, still much greater than is can be perceived by the human eye. A recent study has confirmed that there are significant human physiological differences that result in large differences in perception between, for instance, a group of old and a group of young drivers (8). This particular study cited 50 to 60% differences in the distance that a marking was first observed between the old and young drivers.

The results to date confirm that Laserlux does, in fact, produce repeatable measurements well.

4.2 Roadware Tests

Tests conducted at the Roadware facilities in Paris, Ontario, Canada typically result in repeatability within 5%, for the same two-km stretch of road measured on three consecutive runs with the same Laserlux unit. Figure 10 shows an example of 3 sequential measurement runs conducted recently, in which overall run average retroreflectivities were measured at 275, 276, and 274 mcd/m²/lux. This resulted in 95% confidence limits of less than 1%. Differences between vehicles can usually be attributed to the effects of driving wander (Figure 10).

4.3 FHWA Acceptance Tests

Tests conducted during acceptance trials by the FHWA in 1995 are reproduced in Figure 11. FHWA had purchased five Laserlux equipped vehicles as demonstration units and required them to pass a series of tests on delivery. It was important that not only should each unit prove repeatable with itself over several passes on the same section of highway, but that measurements made by other Laserlux vehicles also show good correlation.

The tests were conducted at the Roadware facility in Kylertown, Pennsylvania, USA, using the five different Laserlux vehicles, measuring a one mile stretch of interstate highway, showed overall run average retroreflectivities of 169, 158, 153, 162, and 176 mcd/m²/lux (Figure 11). This results in 95% confidence limits of about 11%. Measured differences between vehicles in this case were systematic, most likely as a result of differences in calibration.

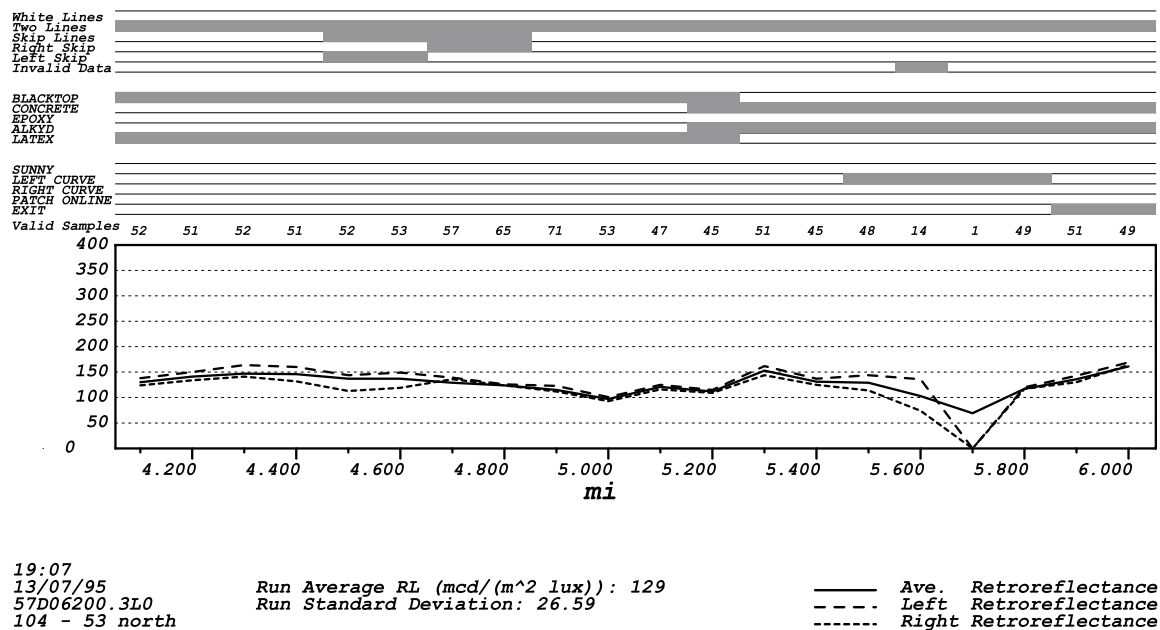


Figure 9 Graphical output of a Laserlux report, showing the left and right stripe retroreflectance values and superimposed event tracks.

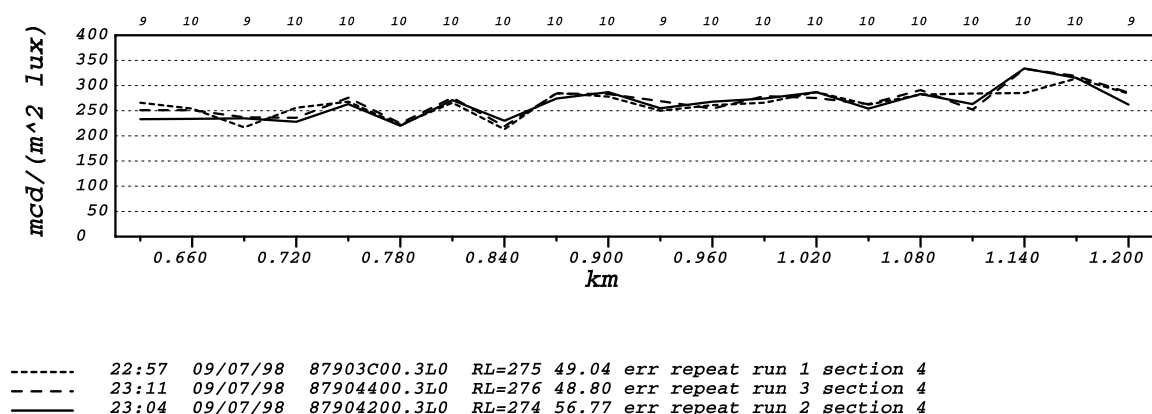


Figure 10. Graphical output of a report for a single Laserlux unit doing repeat runs along the same stretch of highway. Legend shows time, date, file identifier, average retroreflectance in Mcd/m²/lux, standard deviation, and test identifier.

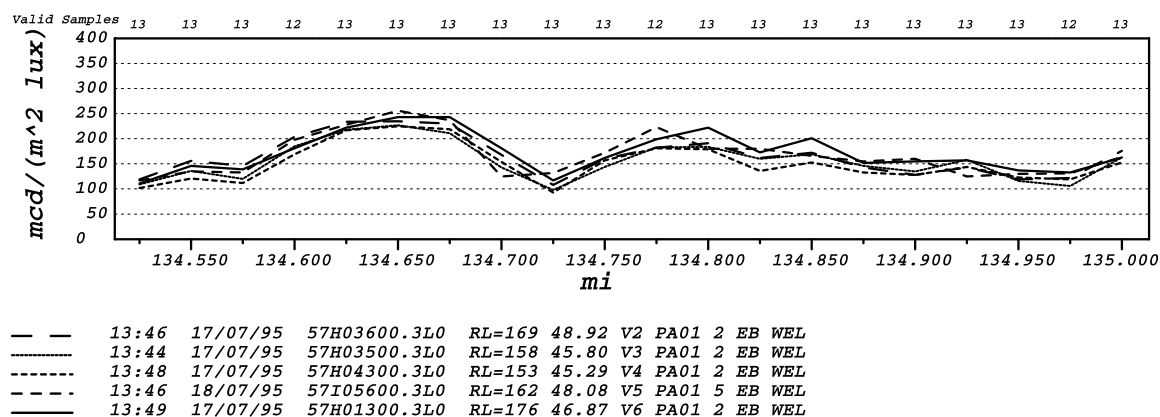


Figure 11. Graphical output of a report for 5 Laserlux units running sequentially along the same stretch of highway. Legend shows time, date, file identifier, average retroreflectance in Mcd/m²/lux, standard deviation, and vehicle and test identifier.

4.3 Independent FHWA Tests

Independent tests conducted by The Federal Highway Administration (6) on three Laserlux units, concluded that the Laserlux retroreflectometers are capable of achieving good levels of repeatability, within the limits of 10 percent tolerance.

4. PAVEMENT STRIPE MANAGEMENT OPPORTUNITES

4.1 Pavement standards

“The U.S. DOT shall revise the Manual on Uniform Traffic Control Devices to include a standard for minimum retroreflectivity for markings and signs and to define the roads that must have center lines and/or edge lines.” ISTEA, Intermodal Surface Transportation Efficiency Act of 1991. The concept of ensuring nighttime visibility on striped roads via legislation has resulted in much research into the needs of drivers of all ages and abilities. While debates occur about what the minimum retroreflectivity should be, how the improvements are to be paid for, and what the overall savings to society by the improvements might be, it has become clear to many researchers that accurate, efficient, statistically significant data collection will be a key to ensuring success of the ISTEA concept.

States that have in place minimum initial quality standards, typically, have used previous standard of use instrumentation, the handheld instrument Mirolux 12. Additional state DOTs (Departments of Transportation) are moving towards initial quality standards of reflectivity. The move towards 30 meter geometry has led to new instrumentation and the minimum initial quality standards for contractor and state applied markings. The shift away from paints that emit VOCs (Volatile Organic Compounds), as required by law, has led to a proliferation of new marking materials. Claims of retroreflectivity and performance life-span are unknown. States are forced to rely on manufacturers claims and independent research. Correlation between test deck performance and actual road performance is conjectural. Incorrect selection of material for a given states ADT (Average Daily Traffic), weather, and budget, can result in poor stripe performance in a much shorter time span than advertised.

Mobile reflectometers, like Laserlux, are essential to the evaluation process by allowing for the evaluation of significantly large samples.

4.2 Re-striping strategies and priorities

Many states still stripe based on the life cycle of alkyd based paints in their area. This limits the state's ability to respond to improvements in life-cycle of new materials, longer or shorter, resulting in re-striping of good markings or not replacing poor markings in a timely manner. Time based re-striping strategies do not incorporate quality as a performance benchmark of striping, only time and labor on an annual basis. This can result in measuring effective performance of a striping operation by line miles per day, rather than how well the markings are visible to the driver over the desired lifetime. States that do re-stripe based on need can save money in the long run. Surveying roads to determine their current reflectivity level, comparing past performance of that material on that type of road, and prioritizing roads that need striping is a plan that is easily accomplished using Laserlux. States that build quality into the striping performance, as a primary objective, find that their stripes last longer.

4.3 Contractor performance.

Minimum initial quality standards appear to be the driving force in changes in reflectivity instrumentation. States are able to place standards to ensure that contractors achieve desired performance over the engineered life span by measuring reflectivity initially, and thereafter. In many cases the cost of the measurement is incorporated into the striping contract. Although the minimum initial retroreflectivity value varies, the concept is the same. Test for acceptability on the road performance rather than testing an incoming material's ability to conform to a laboratory test that may be obsolete. Since the on the road performance test involves only one simple document that is established at the beginning of the contract, it is easier to set up than to change the incoming quality test methods multitude of material tests.

5.4 Emplacement Strategies

While the initial investment in a Laserlux system appears high, a review of the overall use of these systems incorporated into a statewide pavement marking management system, shows that the increase in overall quality of the pavement markings more than pays for the system. Incorporating monitoring of reflectivity and striping log data allows for planning of re-striping based on needs that serve the ultimate customer, the driver. An increase in reflectivity of the pavement markings makes roads safer, saving lives.

Warranty contracts take this concept further, allowing for the monitoring of performance over the engineered life of the marking, allowing for better planning and cost savings. This shift toward monitoring on the road performance rather than incoming material quality, allows states to minimize expensive laboratory testing, saving additional funds. In the end, the driver is really only concerned about the visibility of the pavement marking, not the material.

6. SUMMARY

The ability for quick and efficient measurement of pavement marking retroreflectivity is an important aspect of highway management. It allows standards to be set and maintained, and provides the management tools to do so efficiently and economically. The performance of materials and contractors can be specified and evaluated. Re-striping priorities can be managed as to improve substandard marking, while delaying the re-striping of markings which still meet standards.

Laserlux, a truck-mounted retroreflectometer provides the measurements needed for proper highway pavement marking management. These measurements are quick, simple, reliable, objective, and provide measurements at highway speeds, at data rates high enough for adequate statistical characterization, and without hindering the flow of traffic, nor putting the human operators at undue risk.

This retroreflectometer has demonstrated repeatability within a tolerance of 10% as measured by independent testing. Laserlux measurements provide the accurate and statistically reliable data required for designing pavement standards, implementing striping and re-striping strategies, and evaluating the performance of materials and contractors.

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Instruction Manual

Version 1.8 dated 16.09.2013

Zehntner mapping and data analysis software MappingTools

As from software version 1.15



for following devices series:

ZDR 6020
ZRM 6014
ZRS 6060

Index

Exclusion of liability.....	3
1. Introduction.....	4
1.1 Summary.....	4
1.2 Device type	4
1.3 Standard delivery.....	5
2. Safety precautions and warnings.....	6
2.1 Dangers.....	6
2.2 Notes regarding safety at work.....	6
3. Install/Uninstall.....	7
3.1 System requirements	7
3.2 Installation MappingTools	7
3.3 Removing MappingTools	7
4. Using Zehntner MappingTools.....	8
4.1 Starting-up.....	8
4.2 Components of the main window.....	8
4.3 Job-Browser	9
4.4 Map-Browser	9
4.5 Measurement-Browser	11
4.6 Main-Measurement-View.....	11
4.7 Detail-Data-Browser	14
4.8 Filename extensions.....	17
5. Overview of the menu	18
5.1 Menu "File"	18
5.1.1 Open.....	18
5.1.2 Import.....	18
5.1.3 Save	18
5.1.4 Export	18
5.1.5 Export .XLS.....	18
5.1.6 Copy	19
5.1.7 Save map as a picture.....	19
5.2 Menu "View"	19
5.3 Menu "Measurement"	19
5.3.1 Information Editing	19
5.3.2 Remove from list.....	19
5.3.3 Show in Windows Explorer	19
5.3.4 Generating Report.....	20
5.3.5 Delete 0 Measurements	20
5.3.6 Export .KMZ.....	20

5.4	Menu "Extras"	21
5.4.1	Profile Editor	21
5.4.2	Settings	23
5.5	Menu "Help"	23
5.5.1	Manual	23
5.5.2	About	23
6.	Measurement-report	24
6.1	Generate a report for ZDR 6020 measurements	24
6.1.1	Page orientation	24
6.1.2	Measurement Information	24
6.1.3	Company Logo	25
6.1.4	Data Table	25
6.1.5	Report Viewer	26
6.2	Generating a report of ZRM 6014 or ZRS 6060 measurements	27
7.	Glossary	29

Exclusion of liability

The features described in this instruction manual represent the complete technology of this instrument. Those features are either included in the standard delivery or available as options at additional costs.

Illustrations, descriptions as well as the technical specifications conform to the instruction manual at hand at the time of publishing or printing. However, Zehntner GmbH Testing Instruments policy is one of continuous product development. All changes resulting from technical progress, modified construction or similar are reserved without obligation for Zehntner to update.

Some of the images shown in this instruction manual are of a pre-production model and/or are computer generated; therefore the design/features on the final version of this instrument may differ in various aspects.

The instruction manual has been drafted with the utmost care. Nevertheless, errors cannot be entirely excluded. The manufacturer will not be liable for errors in this instruction manual or for damages resulting from any errors. The manufacturer will be grateful at any time for suggestions, proposals for improvement and references to errors.

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1. Introduction

1.1 Summary

The Zehntner "MappingTools" mapping and data analysis software makes your administration and analysis of road markings measurements and retro-reflective materials, e.g. traffic signs, warning clothes, etc. simple and easy. It also helps you in generating measurement reports.

Features:

- Generating measurement reports
- Save reports as a PDF-file
- Measurements can be exported to Microsoft® Excel
- Measurements containing GPS coordinates can be displayed on a bing™ map in different colours using adjustable profiles as well as alternatively exported to Google Earth™.
- The map can be saved as a picture for using in inhouse reports.

1.2 Device type

The "MappingTools" mapping and data analysis software is made for the following device types:

Device type	Description	Application area
ZRM 6014	Retroreflectometer R_L/Q_d	Portable determination of the night and day visibility of all types of road markings.
ZRS 6060	Retroreflectometer	Portable determination of night visibility of retroreflective materials such as traffic signs, safety garments, contour safety markings, license plates, etc. (depending on device version) .
ZDR 6020	Dynamic retroreflectometer R_L	Dynamic determination of the night visibility of all types of road markings.

Partially the illustrations are used of one device only. Therefore it is possible that the illustration of the same with another device type can be different. Anyway, the illustration can be used as an example.

1.3 Standard delivery

The "MappingTools" mapping and data analysis software is supplied with the device types mentioned in chapter 1.2 "Device type" on page 4.



Zehntner GmbH Testing Instruments rejects any liability and claims under guarantee for damages caused by use of the "MappingTools" mapping and data analysis software.

2. Safety precautions and warnings

2.1 Dangers



Attention!

This note is included in this instruction manual wherever it is warned about dangers which will arise to life and limb of persons if the apparatus is handled improperly. Observe these notes and be particularly careful in these cases. Also inform other users on all safety notes. Besides the notes in this instruction manual the generally applicable safety instructions and regulations for prevention of accidents have to be taken into account.



Caution

This note comprises instructions to be observed in order to comply with guidelines, instructions, notes and the proper procedure of the work, and to avoid data loss.

2.2 Notes regarding safety at work



The "MappingTools" mapping and data analysis software is exclusively designed for presenting road marking measurements and retro-reflective materials, e.g. traffic signs, warning clothes, etc. Any other application is not in accordance with the regulations. The manufacturer is not liable for damage resulting from inappropriate application. The user bears the full responsibility.



Unauthorised modifications and changes of the "MappingTools" mapping and data analysis software are not allowed. The manufacturer is not liable for damages resulting from unauthorised modifications; the user bears the full responsibility.



Zehntner GmbH Testing Instruments refuse any claims of liability and guaranty for any damages caused by the use of the "MappingTools" mapping and data analysis software.



To operate the ZRM 6014, ZRS 6060 and ZDR 6020 please refer to the respective separate instruction manuals.

3. Install/Uninstall

3.1 System requirements

In order to install the "MappingTools" mapping and data analysis software on your PC or laptop, the system shall meet the following minimum requirements:

- Operating system: Microsoft® Windows XP SP2, Microsoft® Windows Vista or Microsoft® Windows 7
- Required components: .NET Framework Version 3.5
Microsoft® Internet Explorer 7
- Memory (RAM): min. 512 MB
Recommended 1 GB
- Hard Disc space: min. 20 MB + space for measurements
- Internet connection: For using the map you need a connection to the internet. If the .Net Framework 3.5 is not installed you need a connection to the internet at the installation.

3.2 Installation MappingTools

The current version can be downloaded for free from our website www.zehntner.com.

Unzip the downloaded file and double click the setup.exe for the installation. At this point Windows will lead you through the remainder of the installation process.

- ! Depending on the configuration of your system, it might be possible that you have to install additional components. The "MappingTools" Setup-Wizard will advise you to do, if necessary. Simply install the desired component by clicking on its corresponding link.

Zehntner recommends that the latest "MappingTools" version will be installed.

3.3 Removing MappingTools

In order to remove the "MappingTools" mapping and data analysis software from your system go to

Start->Settings->Control Panel-> Add/Remove Programs and choose Zehntner "MappingTools" from the list of installed software. Click on "**remove**" to uninstall the program.

4. Using Zehntner MappingTools

4.1 Starting-up

First connect your PC or laptop with the internet otherwise the map will not get loaded. The first time the "MappingTools" mapping and data analysis software will start in English, however the language can be changed in the settings window. Please also refer to chapter 5.4.2 "Settings" on page 23.

It might be necessary to export your measurements on your PC/laptop to get them displayed with the "MappingTools" mapping and data analysis software. For this please consider the separate instruction manual of the respective instrument (ZRM 6014, ZRS 6060 or ZDR 6020). Afterwards the measurements need to be opened like described in chapter 5.1.1 "Open" on page 18.

4.2 Components of the main window

The main window of the "MappingTools" contains several parts illustrated in the picture below and explained in the following chapters.



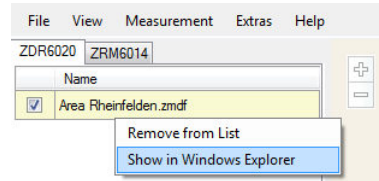
Key:

- (1) Job-Browser
- (2) Map-Browser
- (3) Measurement-Browser
- (4) Main-Measurement-View
- (5) Detail-Data-Browser
- (6) Status bar

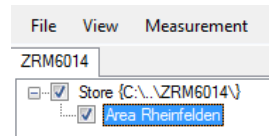
4.3 Job-Browser

A job represents a series of measurements. If a Zehntner data-file is opened or imported the jobs are listed in the tab of the Job-Browser. By checking a job the measurements are displayed in the Measurement-Browser. Every device type has his separate tab.

By a right click on a measurement, the job can either be removed from the Job-Browser or shown in the windows explorer.

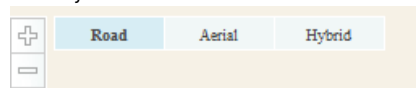


If a data-file contains several jobs the Job-Browser is structured hierarchically. In the file tree you can either select or deselect a single or all jobs.

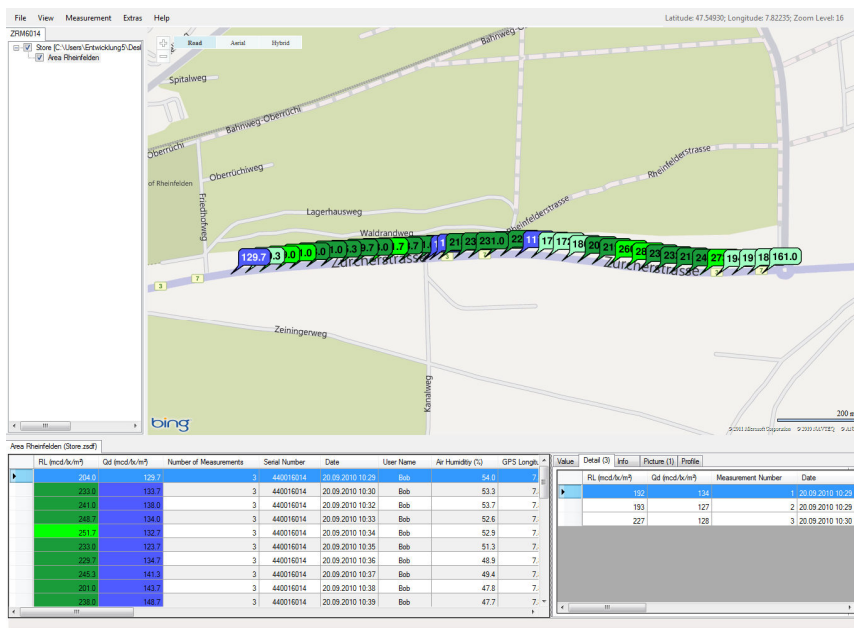


4.4 Map-Browser

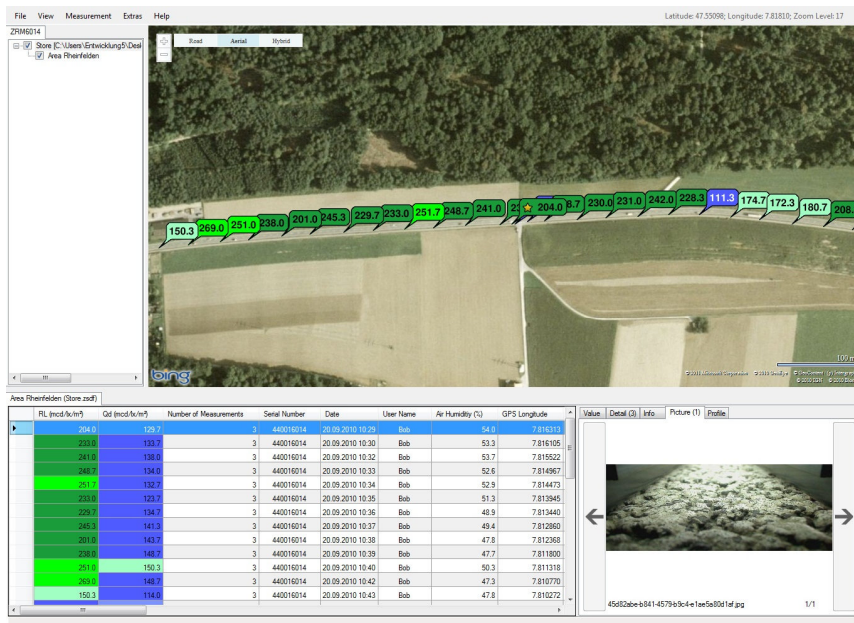
Measurements which are selected in the Measurement-Browser are displayed coloured in the Map-Browser depending on the selected profile. You can switch the view profile between "Road", "Aerial" and "Hybrid".



Road:



Aerial:



- ! The views “Aerial” and “Hybrid” are not available in high resolution on every part of the earth but the “Road View” works everywhere. Alternatively an export to Google Earth™ is provided.
- ! If you zoom in too deep on the map in the view “Road” and there is no element like a street it might be confusing and you have to zoom out.

4.5 Measurement-Browser

The Measurement-Browser illustrates the recording data of a job selected in the Job-Browser. Each selected job has its own separate tab with a Main-Measurement-View and a Detail-Data-Browser.

4.6 Main-Measurement-View

In the Main-Measurement-View the data (a collection of measurements) is displayed line by line in table form. One measurement in the Main-Measurement-View can contain several single measurements. So an illustrated shown value of a geometry in the Main-Measurement-View is an average over all belonging valid single measurements.

Following actions can be carried out:

Multi select:

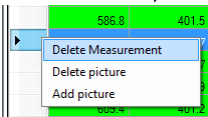
The function “multi select of measurements” can be used to delete measurements or to calculate the mean value. The mean value is shown at the bottom of the status bar.

Area Rheinfelden (Store.zsdf)						
	RL (mcd/tx/m²)	Qd (mcd/tx/m²)	Number of Measurements	Serial Number	Date	Us
	233.0	133.7	3	440016014	20.09.2010 10:30	
	241.0	138.0	3	440016014	20.09.2010 10:32	
	248.7	134.0	3	440016014	20.09.2010 10:33	
	251.7	132.7	3	440016014	20.09.2010 10:34	
	233.0	123.7	3	440016014	20.09.2010 10:35	
	229.7	134.7	3	440016014	20.09.2010 10:36	
	245.3	141.3	3	440016014	20.09.2010 10:37	
	201.0	143.7	3	440016014	20.09.2010 10:38	
	238.0	148.7	3	440016014	20.09.2010 10:39	
	251.0	150.3	3	440016014	20.09.2010 10:40	
	269.0	148.7	3	440016014	20.09.2010 10:42	
RL mean: 223.2 [2/2] Qd mean: 142.5 [2/2]						

Left mouse click: By a left mouse click on a measurement, the map will change its view to this section. The measurements can be sorted in ascending or descending order by clicking on the header of a column.

Left mouse double click: The views in the Detail-Data-Browser can be changed.

Right mouse click on row: With this action you can choose between delete measurement, delete picture and add picture.

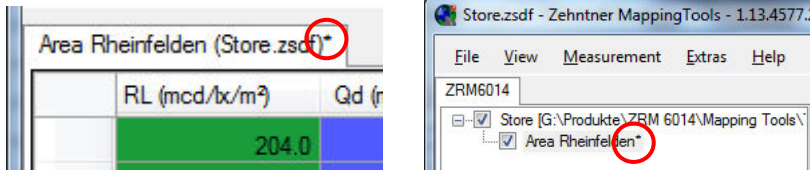


The deletion and adding of pictures is only possible for *.ZSDF files.

Area Rheinfelden (Area Rheinfelden.zmdf)			Area Rheinfelden (Store.zsdf)							
	Position (km)	Date	RL (mcd/s/m²)	RL Min (mcd/s/m²)	RL Max (mcd/s/m²)	RL α (mcd/s/m²)	RL Pass (%)	Temperature (°C)	Humidity (%)	Speed (m/s)
	0.200	20.09.2010 10.00.34	140	96	156	5	86	22	41	17.792
	0.250	20.09.2010 10.00.37	161	100	266	11	98	22	42	18.569
	0.300	20.09.2010 10.00.39	255	194	272	2	100	23	44	19.292
	0.350	20.09.2010 10.00.42	234	169	252	13	99	23	45	19.878
	0.400	20.09.2010 10.00.44	207	175	232	4	100	22	47	19.617
	0.450	20.09.2010 10.00.47	246	196	250	3	99	22	46	19.39
	0.500	20.09.2010 10.00.49	228	205	262	9	99	22	43	20.025
	0.550	20.09.2010 10.00.52	257	165	272	4	99	22	42	20.097
	0.600	20.09.2010 10.00.54	231	171	234	3	99	22	41	20.436
	0.650	20.09.2010 10.00.57	246	131	251	5	99	23	41	20.361
	0.700	20.09.2010 10.00.59	236	63	242	5	79	22	41	20.4
	0.750	20.09.2010 10.01.02	229	201	275	9	100	22	42	20.4
	0.800	20.09.2010 10.01.04	216	151	223	6	95	22	42	20.45
	0.850	20.09.2010 10.01.07	247	196	252	4	99	21	43	20.464
	0.900	20.09.2010 10.01.09	209	120	231	17	99	22	43	20.4
	0.950	20.09.2010 10.01.12	140	115	173	4	100	22	43	20.4
	1.000	20.09.2010 10.01.14	163	146	184	3	100	22	42	20.361
	1.050	20.09.2010 10.01.16	192	168	225	4	100	22	42	20.147
	1.100	20.09.2010 10.01.19	217	165	223	6	99	22	42	19.878

RL mean: 229.0 [3/3]

A modification of a job in the Main-Measurement-View, respectively, the deletion of measurements is indicated by a star in the tab of the Measurement-Browser and in the Job-Browser.



The star will disappear when the job is saved.

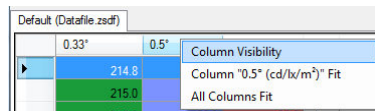
If a picture is deleted the picture will be removed from the picture folder, if the picture is not assigned to another measurement.

A picture will be inserted by copying the picture from the source folder to the destination folder. If there is already a picture, this picture, will be replaced and removed if it is not dedicated to another measurement. If a picture with an already existing name and same picture format, not located in the picture folder, is inserted the current picture with the same name will be overridden.

The picture will be copied only and represented as relative scaled in the software. The resolution and the size will be unchanged.

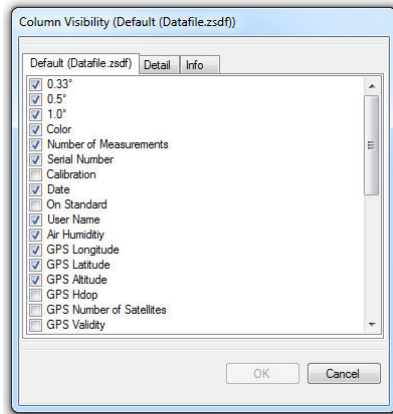
Right mouse click column:

With this click you can choose if you get to the form of column visibility, adapt the selected column width or all column width.



Column visibility:

Define which column is visible.

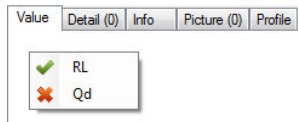


4.7 Detail-Data-Browser

The Detail-Data-Browser contains more detailed and descriptive information about a selected measurement in the Main-Measurement-View. Depending on the device type the Detail-Data-Browser differs with the numbers of views.

The following views exist:

Value: The Value view presents the geometry values of the actual selected measurement, as well as the maximum and the minimum value. If more than one geometry exists, a geometry can be hidden with a right mouse click on the tab or the space key.



Detail: The Detail-view shows the information of the single measurements (single or average measurements) in table form. Like in the Main-Measurement-View the delete function is provided.

Value	Detail (3)	Info	Picture (1)	Profile
	RL (mcd/bc/m²)	Qd (mcd/bc/m²)	Measurement Number	Date
▶	235	137	1	20.09.2010 10:57
	230	137	2	20.09.2010 10:58
	225	121	3	20.09.2010 10:58

Info: The Info-View shows the additional information to a measurement and helps to edit the information.

Value	Detail (0)	Info*	Picture (0)	Profile
	Description	Information		
✎	Location	Sissach		
	Street			

Picture: This view shows the picture which belongs to the selected measurement. A click on the picture opens an enlarged view in a separate window with enlarged view. A click on the picture name opens the explorer with the actual selected picture.

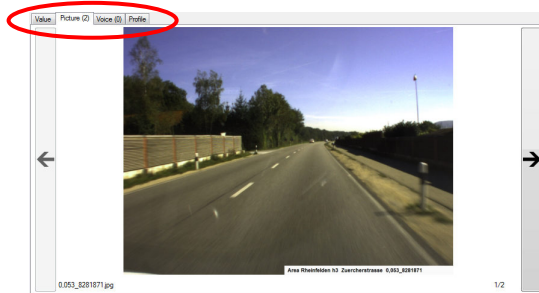
Air Humidity (%)	GPS Longitude
53.3	7.8161
53.7	7.8155
52.6	7.8149
52.9	7.8144
51.3	7.8139
48.9	7.8134
49.4	7.8128
47.8	7.8123
47.7	7.8118
50.3	7.8113
47.3	7.8107

Value	Detail (3)	Info	Picture (1)	Profile
				
dc6c705d-0a31-4d42-8708-8ba33c5f21a2.jp				1/1

Voice: With the Voice-View, voice recording can be played back.

Profile: This Profile-view depends on the device type. It is possible to assign a different profile to R_L than to Q_d. Only R_L or only Q_d are shown on the map depending on the selection. This also applies for the different observation angles of the ZRS 6060.

Some views include additional information in the tab.



To change the view, click on another tab or double click the measurement in the Main-Measurement-View.

4.8 Filename extensions

Data file	Device / program
*.KMZ	Google Earth file exported from a *. ZMDF or *. ZSDF-file. Please also refer to chapter 5.3.6 on page 20.
*.PDF	- PDF reports exported from "MappingTools"-files from ZDR 6020 Please also refer to chapter 6.1 on page 24. - PDF reports exported from "MappingTools"-files from ZRM 6014 or ZRS 6060 Please also refer to chapter 6.2 on page 27.
*.PNG	Picture format if the current map view in the Map-Browser is exported. Please also refer to chapter 5.1.7 on page 19.
*.XLS	- Original measurement file of the ZDR 6020 Please also refer to chapter 5.1.2 on page 18 and chapter 5.1.5 on page 18. - Excel-report-export-file from "MappingTools"-files from ZDR 6020 Please also refer to chapter 6.1 on page 24. - Excel-report-export-file from mapping tools measurement files from ZRM 6014 or ZRS 6060 Please also refer to chapter 6.2 on page 27.
*.ZMDF	"MappingTools"-file with ZDR 6020-measurement data Please also refer to chapter 5.1.1 on page 18 and chapter 5.1.2 on page 18
*.ZMTP	"MappingTools"-profile file Please also refer to chapter 5.4.1 on page 21.
*.ZSDF	- Original measurement file of the ZRM 6014 - Original measurement file of the ZRS 6060 "MappingTools"-file with measurement data from ZRM 6014 or ZRS 6060 Please also refer to chapter 5.1.1 on page 18 and chapter 5.1.6 on page 19. Should you not be able to open .ZSDF files and you have a 64-bit operating system, please install „Microsoft SQL Server Compact 3.5 Service Pack 2 for Windows Desktop“. This error occurs if a different Microsoft SQL Server Compact is installed. Please contact Zehntner if this would not solve the issue.

5. Overview of the menu

The menu items are changing depending on the device type. So as mentioned not every functionality can be chosen for every device.

5.1 Menu "File"

5.1.1 Open

This menu item allows you to load an existing "MappingTools"-file (*.ZMDF, *.ZSDF).

Should you not be able to open .ZSDF files and you have a 64-bit operating system, please install „Microsoft SQL Server Compact 3.5 Service Pack 2 for Windows Desktop“. This error occurs if a different Microsoft SQL Server Compact is installed. Please contact Zehntner if this would not solve the issue.

5.1.2 Import

Import an existing original measurement file of the device ZDR 6020 as a Microsoft® Excel-file. With each import a ZMDF-file will automatically be generated in the same directory where also the XLS-file lies. ZMDF is a new file format for storing measurements and gives more possibilities to maintain ZDR 6020 measurements with the "MappingTools" mapping and data analysis software.



The structure of an original measurement must not be changed. It has to be a tab separated XLS-file otherwise the import will not work properly.

5.1.3 Save

This menu item allows you to "Save" or to "Save as" the current selected measuring file. To save all jobs in the Measurement-Browser "Save all" can be used.

5.1.4 Export

The function "Export" in the file menu is used to convert open or imported data to generate a file which is compatible with another program.

5.1.5 Export .XLS

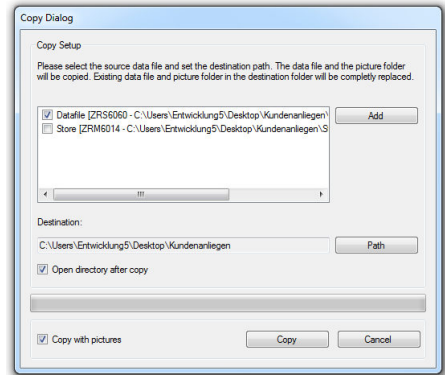
This menu item is used to convert into a ZMDF-file to a Retro-Grabber compatible XLS-file. The Retro-Grabber is the operating software of ZDR 6020.

5.1.6 Copy

This menu-item is used for copying a ZSDF-file from one place in the file system to another. To keep the data consistence, the "PICS" folder and a data-file with the same name (if existing) will be completely replaced in the destination directory.

It is possible to add data-files of other storage locations.

Determine if the pictures should be copied too or only the data-file.



Tick the "Open directory after copy" to open the directory directly after the copy.

5.1.7 Save map as a picture

This menu item allows you to save the current view in the Map-Browser as a picture (*.PNG).

5.2 Menu "View"

The menu item view includes the possibility to display or hide the map, the Measurement-Browser or Job-Browser by ticking.

5.3 Menu "Measurement"

Basically this menu item is only activated, if at least one job is displayed in the Measurement-Browser.

5.3.1 Information Editing

This menu item allows editing the header information from the selected job.

5.3.2 Remove from list

This menu item removes the current selected job in the Job-Browser.

5.3.3 Show in Windows Explorer

This menu item shows the data-file of the selected job in the Windows Explorer.

5.3.4 Generating Report

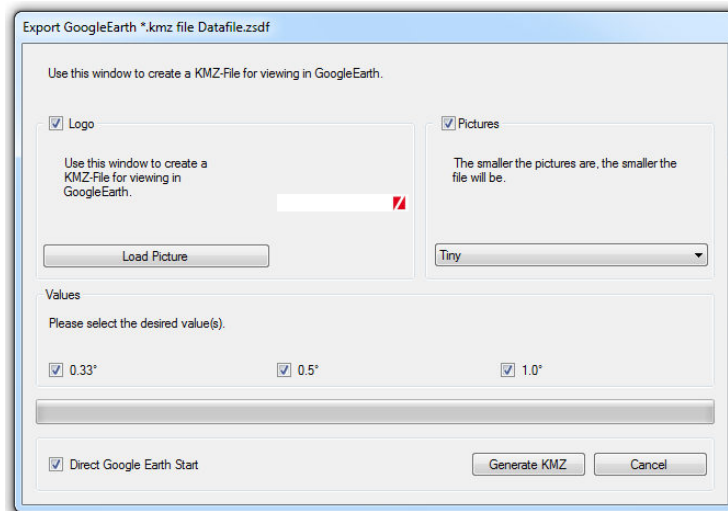
This menu item will generate a measurement report from the selected job. There are two types of reports depending on the device. One report is a PDF-output the other a Microsoft® Excel-file. For further information refer to chapter 6 "Measurement-report" on page 24.

5.3.5 Delete 0 Measurements

Use this menu item to delete all invalid measurements in the Main-Measurement-View.

5.3.6 Export .KMZ

This menu item is used to export a job as a KMZ-file to display the measurements in Google Earth. Define the value range. Feel free to add a logo and to decide the size of the pictures. A progress bar shows the status during the file's generating. Start Google Earth directly by checking "Direct Google Earth Start".



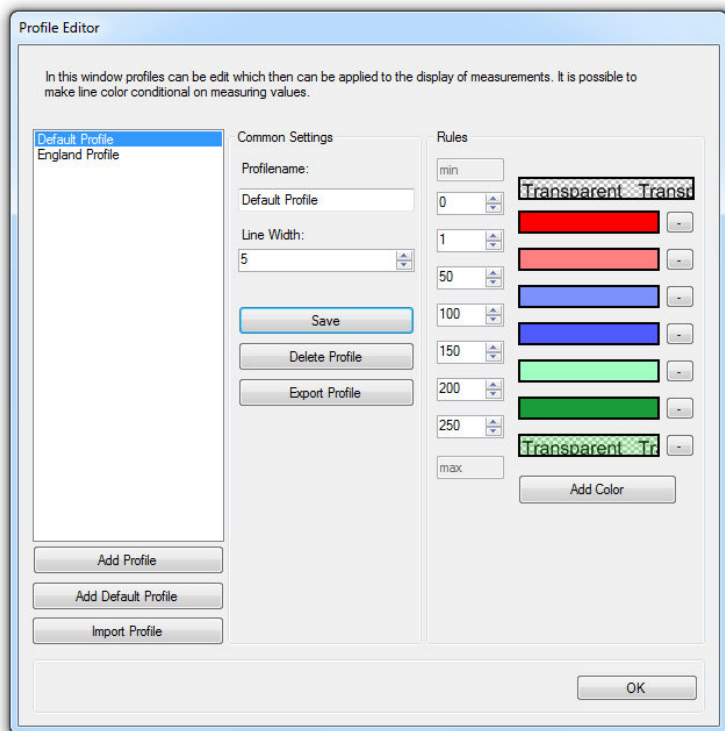
5.4 Menu “Extras”

5.4.1 Profile Editor

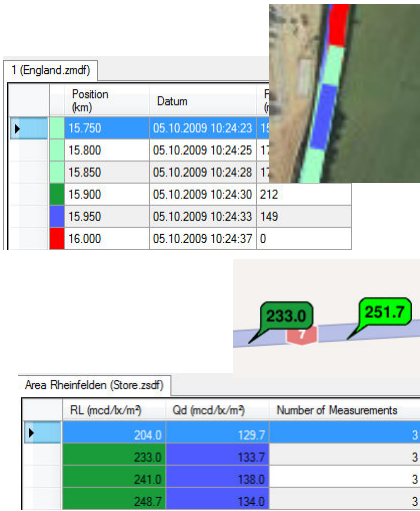
This menu item will open an editor window in which different colour profiles can be added or changed.

To create a new profile click on the “Add Profile” button, set a new name in the “Profile name” textbox, change and/or add colours and values to the rule and save it. There must be always one profile, therefore with “Add Default Profile” the direct generation of a profile is provided.

Colours can be changed by clicking on the coloured boxes.



The colours of the selected profile are displayed on the map and in the Main-Measurement-View:



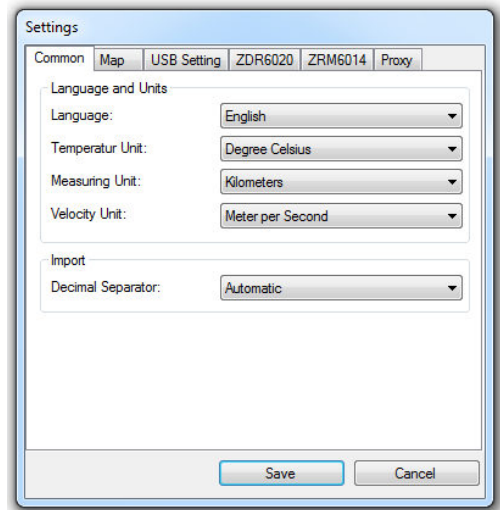
These profiles are stored locally on the PC/laptop. So if you want to use the same profile on another PC/laptop, then you can use the "Export Profile" and "Import profile" function.

5.4.2 Settings

The global program settings are structured by tabs in a common, map and device specific part (ZRM 6014 or ZDR 6020).

Several settings can be set such as language, units, appearance and reaction on events.

The device-specific settings for the ZRS 6060 will be made directly in the Measurement-Browser with a right mouse click on the data columns.



Only use the proxy settings if you use a proxy in your network.

5.5 Menu “Help”

5.5.1 Manual

If an instruction manual of the selected language exists, the instruction manual can be displayed over this menu item or by pressing the key “F1”. Otherwise the English instruction manual is displayed.

5.5.2 About

Software information like the version is displayed here.

6. Measurement-report

One of the software's features is the possibility to generate reports. Depending on the device, the output file is a PDF- or a Microsoft® Excel-file.

6.1 Generate a report for ZDR 6020 measurements

For generating a ZDR 6020 measurement report select a job in the Job-Browser and open the "Generate Report" window over the menu **Measurement->Generate Report**.

Generate Report

Chose in this window which data should be displayed and printed in the report and click afterwards on "Generate Report".

Pageorientation
☒ Portrait ☐ Landscape

Measurement Informationen
Common information which will be displayed on the first side of the report.

☒ Region ☐ Client Name
☒ Street ☐ OrderID
☐ Direction ☐ Retro Grabber Version
☒ Startposition ☒ Firmware Version
☐ Interval ☒ Total length
☐ Line
☐ Side
☒ Driver
☐ Comment
☐ Order Date

☒ Company Logo
Load Picture

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☒ Datable
Columns which will not be displayed in the report are on the left side, columns which will be displayed are on the right. There is a automatic limitation of data presented by grey items.

Endposition
Marker
Reference
RL or
Speed
Startposition
Temperature

Position
Date
RL
RL Max.
RL Min.
RL Pass
Humidity

Generate Report Cancel

In this window you are able to change some settings for the measurement report.

6.1.1 Page orientation

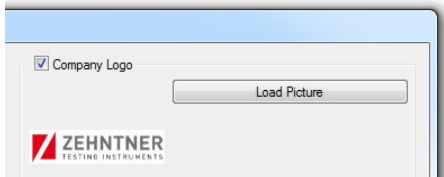
Here the page orientation can be set.

6.1.2 Measurement Information

In the measurement information section it is possible to choose the header information displayed on the first page of the measurement report.

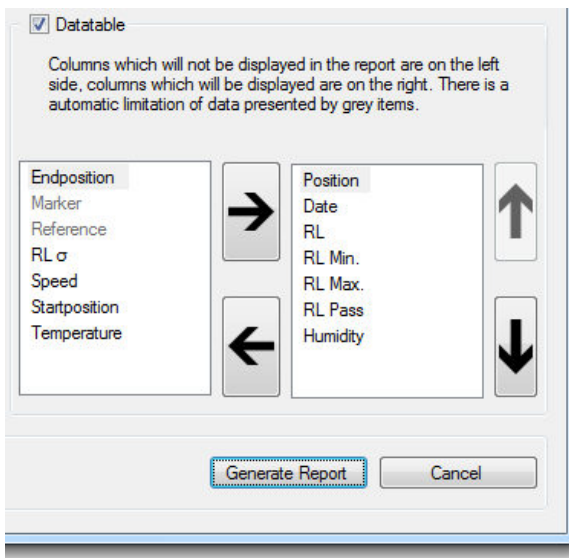
6.1.3 Company Logo

If the “Company Logo” function is activated, a logo in the formats BMP, JPG, GIF or PNG can be chosen. The company logo will appear on the first page of the measurement report.



6.1.4 Data Table

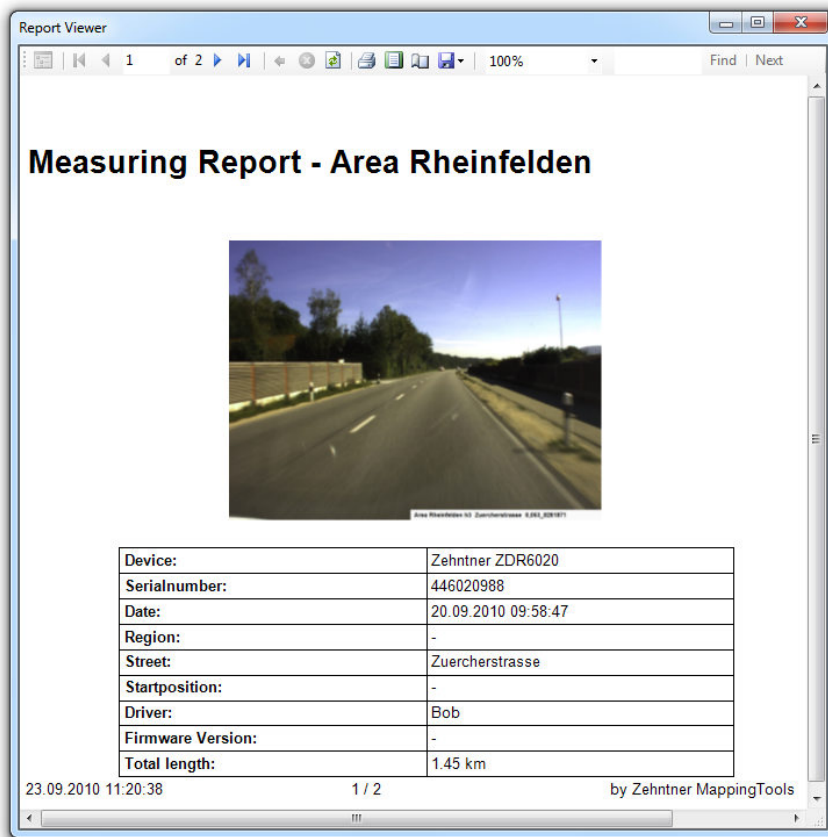
If the data table section is activated, a data section will be appended to the measurement report with more detailed information. Data columns can be moved from the left text box to the right, which represents the measurement report. With up and down arrows the column order can be defined. The number of columns available to choose depends on the page orientation. If there is not enough space on the measurement report, the columns are disabled and cannot be chosen.



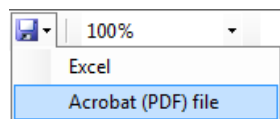
6.1.5 Report Viewer

In the "Report Viewer" window a preview will be shown on two sites. On this window the report can be printed or saved as a .PDF or .XLS-file.

By clicking on this icon  in the menu the current view will change to a print view.



Over the save icon the report can be saved in the PDF format. You are able to save the report as an .XLS-file if you choose „Excel“.



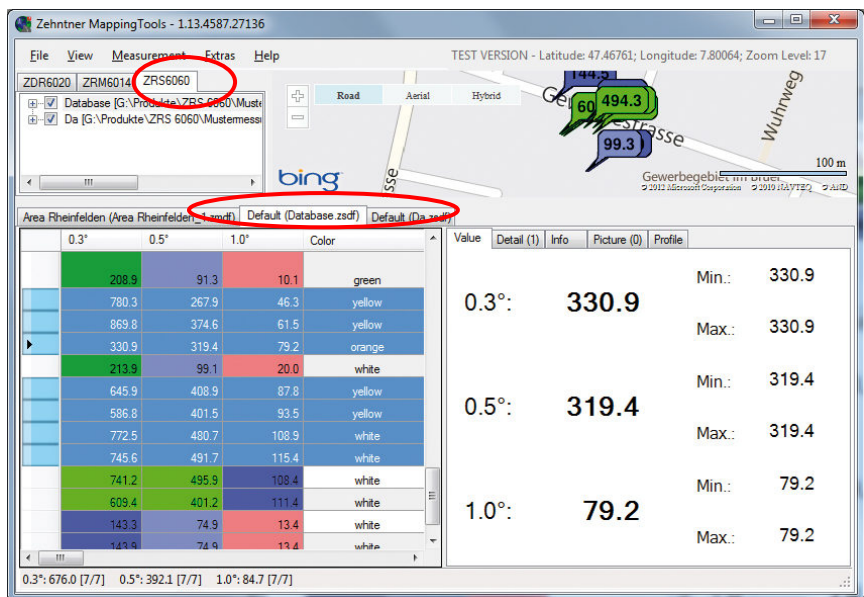
6.2 Generating a report of ZRM 6014 or ZRS 6060 measurements

With the devices ZRM 6014 and ZRS 6060 you are able to choose which jobs or which measurements of a specific job shall be displayed in the measuring report. You can choose from the following options:

- „All listed measurements“ (all measurements of the selected job)
- „Actual selected measurement(s)“ (only the actual selected measurements of the selected job displayed in the Main-Measurement-View)
- „Content of all open tabs“ (all open jobs of the same device version of the actual selected job)

The desired jobs must be opened and if desired the required measurements must be selected.

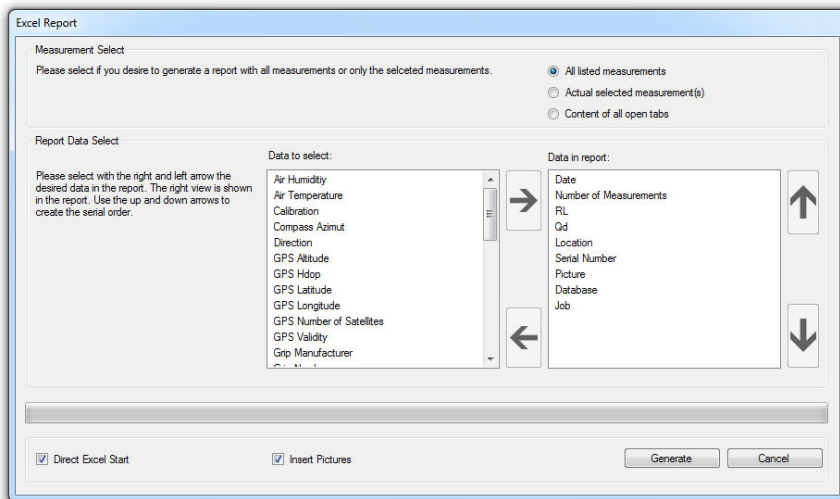
In the sample below, the device type ZRS 6060 and its job “Default” is selected where 7 single measurements are also selected. Furthermore, a second job of a ZRS 6060 is opened. As both jobs contain measurements of the same device version (6060.CEN), both can be displayed in the same measuring report if you choose the function “Content of all selected jobs”.



The generating of a ZRM 6014 or ZRS 6060 measurement report can be selected over **Measurement->Generate Report**.

Depending on your selection of the jobs and the single measurements, you are able to choose which jobs or which measurements of the jobs can be exported.

You can choose between „All listed measurements“ (all measurements of the selected job), „Actual selected measurement(s)“ (only the actual selected measurements of the selected job displayed in the Main-Measurement-View) „Content of all open tabs“ (all open jobs of the same device version of the actual selected job).



In this sample „All listed measurements“ was chosen. This means that all measurements of the job “Default” of the device version 6060.CEN will be displayed in the measuring report.

If all open jobs are exported to the Excel-file the order is given by the order of the open jobs.

With the arrows left/right the data for the report can be selected or deselected. The serial order can be controlled with the arrows up/down.

During the generating of the Microsoft® Excel-file the status is represented in the progress bar. To open the excel sheet directly afterwards tick “Direct Excel Start”.

The direct insertion of the picture not only as name is activated by selecting the “Insert Pictures”.

If you have a PDF creating software you can generate a PDF-file from the Microsoft® Excel-file.

7. Glossary

A

About 23

B

Browser

Detail-Data 14
Job 9
Map 9
Measurement 11

C

Company Logo 25
Copy 19

D

Data Table 25
Delete 0 Measurements 20
Detail-Data-Browser 14

E

Editing information 15, 19
Exclusion of liability 3
Export 18
 GoogleEarth .KMZ 20
 Microsoft® Excel ZDR 6020 18
 Microsoft® Excel ZRM 6014 27
 Microsoft® Excel ZRS 6060 27
 PDF ZDR 6020 24
 PDF ZRM 6014 29
 PDF ZRS 6060 29
Extras 21

F

Filename extensions 17

G

Generating

Report 20
Google Earth™ 20

H

Help 23

I

Import 18
Information Editing 19
Install 7
Instruction manual 23
Introduction 4

J

Job-Browser 9

L

Logo 25

M

Main-Measurement-View 11
Manual 23
Map-Browser 9
MappingTools
 Install 7
 Starting-up 8
 System requirements 7
 Uninstall 7
Measurement
 Information 25
 Report 24
Measurement report
 PDF ZDR 6020 24
 PDF ZRM 6014 27
 PDF ZRS 6060 27
 XLS ZDR 6020 24
 XLS ZRM 6014 27
 XLS ZRS 6060 27
Measurement-Browser 11

Menu

<i>Extras</i>	21
<i>File</i>	18
<i>Help</i>	23
<i>Import</i>	18
<i>Measurement</i>	19
<i>Open</i>	18
<i>Overview</i>	18
<i>Save File</i>	18
<i>View</i>	19

O

Open	18
Overview of the menu	18

P

Page orientation	24
PDF-Report	
<i>PDF ZDR 6020</i>	24
<i>PDF ZRM 6014</i>	27
<i>PDF ZRS 6060</i>	27
Picture	15, 19
Profile editor	21

R

Remove from list	19
Report	24
<i>Generating</i>	20
<i>PDF ZDR 6020</i>	24
<i>PDF ZRM 6014</i>	27
<i>PDF ZRS 6060</i>	27
<i>Viewer</i>	26
<i>XLS ZDR 6020</i>	24
<i>XLS ZRM 6014</i>	27
<i>XLS ZRS 6060</i>	27

S

Safety precautions and warnings	6
Save	
<i>As a PDF-file</i>	26
<i>File</i>	18
<i>Map as picture</i>	19
Settings	23
Starting-up	8
System requirements	7

T

Test report	24
<i>PDF ZDR 6020</i>	24
<i>PDF ZRM 6014</i>	27
<i>PDF ZRS 6060</i>	27
<i>XLS ZDR 6020</i>	24
<i>XLS ZRM 6014</i>	27
<i>XLS ZRS 6060</i>	27

U

Uninstall	7
Using Zehntner MappingTools	8

V

View	19
-------------------	----

W

Windows Explorer	19
-------------------------------	----

X

XLS-Report	
<i>XLS ZDR 6020</i>	24
<i>XLS ZRM 6014</i>	27
<i>XLS ZRS 6060</i>	27

제7장. 연구개발성과의 보안등급

가. 보안등급의 분류

보안	일반
	○

나. 결정사유

기초기술을 기반으로 한 응용개발기술로써 일반 보안등급에 해당됨.

제8장. 국가과학기술종합정보시스템에 등록된 연구시설·장비 현황

구입 기관	연구시설/ 연구장비명	규격 (모델명)	수량	구입 연월일	구입 가격 (천원)	구입처 (전화번호)	비고 (설치 장소)	NTIS장비 등록 번호
제 일 자 동화	동적각도변화 생성장치	개발장비	1	20120822	15,499	제일자동화 (010-4624- 0978)	경기도 안산 시 상록구 해 안로 705 (사동) (주)로 드텍 경기테 크노파크 RIT 센터 2층	NFEC-2013-05 -178945
인 성 인 터 내 쇼 날	관성항법장치	IMU-FSAS-EI -O	1	20130620	44,000	인성인터내쇼 날 (02-579-50 31)	경기도 안산시 상록구 한양대 학로 55 (사동) (주)로드텍 포장가속시험 동(조사차량) 1층	NFEC-2013-11 -183829
지 오 시 스템	광대역 스캐너	NFEC-2014- 05-188057	1	20140422	78,000	지오시스템 (02-702-76 00)	경기도 안산시 상록구 해안로 705 (사동) (주)로드텍 경기테크노파 크 RIT센터 2층 203	NFEC-2014-05 -188057

제9장. 연구개발과제 수행에 따른 연구실 등의 안전 조치 이행 실적

가. 담당부서 : (주)로드텍 관리팀

나. 담 당 자 : 대표이사 문 형 철

다. 안전조치 이행사항

(1) 연구실 안전관리규정 비치

(가) 법령, 안전관리규정, MSDS, 비상연락망, 연구실 안전수칙 비치 및 게시

(나) 대상 : (주)로드텍 업무 공간 (경기테크노파크 RIT센터 203~205호)

(2) 안전점검 실시

(가) 연간 1회 이상 의무적으로 실시 (경기테크노파크 시설팀)

(나) 자체 안전점검 실시 후 연구실 위험 요소, 전기시설 등 보완설치

(다) 정밀안전진단 결과에 의거 전기 및 안전시설 등 보완설치 진행

(3) 안전교육 실시

(가) 로드텍 소속 임직원은 월 1시간 이상 안전교육 실시

(나) 일시 : 매월 첫째주 월요일

(다) 장소 : 로드텍 회의실

(라) 참석인원 : 13명

(마) 교육내용 : 연구실 안전환경 조성에 관한 법률, 연구실 유해, 위험요인 등



(4) 연구실 안전시설 보완

(가) 위험물 안전표시 부착

(나) 각 호실에 소화기 배치

제10장. 연구개발과제의 대표적 연구 실적

번호	구분 (논문/특허/ 기타)	논문명/특허명 /기타	소속 기관명	역할	논문 게재지/ 특허 등록 국가	영향력 지수	논문 게재일 /특허 등록일	사사 여부 (단독 사사 또는 중복 사사)	특기 사항 (SCI 여부/인용 횟수 등)
1	특허	특정 주파수 영역의 조명을 이용하여 외란광을 차단하는 카메라 장치 (10-2015-011 8962)	주식 회사 로드텍		대한 민국		2015.08.24. (출원)		
2	특허	차선 재귀 반사 휘도 측정 시스템 및 방법 (10-2016-009 9985)	주식 회사 로드텍		대한 민국		2016.08.05. (출원)		
3	프로그램 등록	차선도색 상태 조사프로그램 (C-2015-020 080)	주식 회사 로드텍		대한 민국		2015.08.26		
4	프로그램 등록	차선도색 휘도 및 상태 조사프로그램 (C-2016-019 025)	주식 회사 로드텍		대한 민국		2016.08.04		
5	프로그램 등록	차선품질 유지관리 프로그램 (C-2016-019 026)	주식 회사 로드텍		대한 민국		2016.08.04		

제11장. 기타 사항

제12장. 참고 문헌

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주 의

1. 이 최종보고서는 국토교통부에서 시행한 국토교통기술사업화 지원사업의 연구보고서입니다.
2. 이 최종보고서 내용을 발표하는 때에는 반드시 국토교통부에서 시행한 사업의 연구개발성과임을 밝혀야 합니다.
3. 국가과학기술 기밀 유지에 필요한 내용은 대외적으로 발표 또는 공개하여서는 안 됩니다.