Quantifying and Improving the Performance of Road Markings

Transfund New Zealand Research Report No.177

Quantifying and Improving the Performance of Road Markings

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Transfund New Zealand Research Report No. 177

ISBN 0-478-11585-7
ISSN 117-05-74

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Dravitzki, V., Potter, S., Loader, M. & Walton, D. 2001. Quantifying and improving the performance of road markings. *Transit New Zealand Research Report 177*. 65 pp.

Keywords: road marking paint trials, retroreflective measurement, skid resistance, test methods, test repeatability, New Zealand, M/7 specification.

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Executive Summary

Key tests used to quantify the performance of road markings in New Zealand give uncertain results. This project was undertaken between July 1999 and June 2001 to establish reliable tests by which the performance of road markings can be assessed. These tests can then be used by roading authorities in specifying performance, and by contractors and manufacturers to improve products.

The project had three objectives:

- to establish the repeatability and reproducibility of measurements of night-time reflectivity of markings over chipseal surfaces,
- to determine the reliability of a laboratory test for the skid resistance of paint markings, and
- to establish the consistency of paint field trials over chipseal surfaces.

Retroreflectometer Measurements

Tests for night-time reflectivity involve the use of a retroreflectometer, which directs light onto the road marking at a low angle and records the light reflected at a similarly low angle. The values obtained are highly variable, and appear to be instrument-specific. Calibration of the instruments against recognised national standards would be the normal way of resolving this variability. However, at the start of this project in 1999 none were suited. A system was therefore developed which allows retroreflectometer readings, which show a wide range of raw values, to be corrected to a common base. This increases measurement consistency and can be used as an interim measure until a calibration system accessible to New Zealand users is available.

A New Zealand study established in 1993 that road markings in this country should have a minimum level of retroreflectivity of 100 $mCd.m^{-2}.Lux^{-1}$. At the same time readings were taken on four retroreflective plates with retroreflectivities straddling the range provided by most markings. The numbers obtained can be used as a common base: by measuring on the same plates with other instruments, conversions to the common base can be developed.

A study was then undertaken to establish the repeatability and reproducibility of the retroreflectometers used when measuring typical road markings in New Zealand. Eight reflectometers were used in the trial: two Mirolux 12s, four Mirolux 7s and two MX 30s. A routine statistical analysis (considering site, instrument, operator, repetitions, and combinations of these) was carried out to determine the significant factors causing variance and influencing repeatability and reproducibility.

It was found that, when measuring on the road, there is significant variability in the readings obtained. Significant sources of error are the instrument/operator combination and the variability of paint reflectivity at the micro level. Repeatability after 10–20 readings is acceptable at about 10%, and slowly gets more accurate when many more readings are taken. Reproducibility is poor and remains at about 30% even when many readings are taken.

Several recommendations are made to increase measurement consistency.

Laboratory Skid Resistance Test for Paints

Skid resistance is an important property of road markings, as they can greatly reduce the skid resistance of the road surface over which they are applied. An interim test to identify the initial skid resistance of road-marking paint is included in the Transit New Zealand Specification TNZ M/7, which is used to approve types of paint for use on the national highways. In this test a metal plate, approximately 150 x 150 mm, is placed on the road surface as the test line is applied, and the skid resistance is later measured in the laboratory using the British Pendulum Tester. The present study investigated this test, as there was uncertainty as to:

- its consistency, and
- its relationship to on-road performance.

Test plates for waterborne acrylic, chlorinated rubber and alkyd paints (the three main types used to mark New Zealand roads) were obtained as part of the paint field trials in Part III of this project, and tested in the laboratory using the British Pendulum Tester. To establish the relevance of testing the skid resistance of a paint over a metal plate compared with the skid resistance of the same paint over a road surface, skid tests were made on road sections painted with the paints used in the field trials. The road sections included: asphalt with moderate and heavy residual previous layers of paint; heavy residual paint layers over grade 4/5 chip; moderate residual layers of paint over grade 3 chip; and previously unpainted grade 3 chip.

It was found that this method of defining the skid resistance of a painted line was variable within a typical 95% confidence interval of ±5 BPN (British Pendulum Numbers). It was also found that a bigger sample – three samples each of three painted plates – is necessary. If confidence is required that almost all paint (95%) will pass a required value, such as 30 BPN, the target mean needs to be increased to 36 BPN or greater based on the mean of three samples.

It was also found that this laboratory skid test correlates to on-road values. New markings laid over previously painted markings on low- to medium-textured road surfaces have skid resistance values similar to but a little larger than values obtained over the metal plate. Paint with skid resistance values of 30 to 36 BPN on the metal plate can often have skid resistance values of less than 45 BPN on previously painted surfaces (45 BPN is now the minimum accepted value in Transit New Zealand specifications). If 45 BPN is to be attained with certainty on the road, then either the skid resistance of paint films as determined by this test needs to be increased to about this value, or additives that enhance skid resistance need to be added to the paint on application.

Paint Field Trial

Paint field trials in New Zealand are carried out on chipseal surfaces, the dominant road surface. Experience has raised concerns about the consistency of the trials with regard to:

- similar results from successive tests,
- tests at different locations,
- tests at different times of the year,
- varying application methods and equipment.

The experiment was intended to develop an understanding of how issues that arise during field trials may cause variability in the results. The variables investigated were: site, season of application, time of day, day-to-day variability, thickness, application and paint type. The design of the experiment is detailed in the main report.

It was found that the paint field trial currently used to assess paint performance for type approval (TNZ M/7) shows significant variability. The test site and season of application are major sources of variability. Conditions on the day and paint film thickness also had some effect for some paint types. Time of day of the application had no significant effect. It was also found that the field trial, although variable, is systematic. Three paints whose performance was expected to range from marginal to very good were included, and the trial clearly distinguished their relative performance.

Paint field trials represent an effective way for manufacturers to gain knowledge of the performance of paint formulations and to guide formulation development. Repeat trials in which the conditions are varied provide a systematic way of identifying the paint's sensitivity to conditions. It is recommended that the trial procedure of TNZ M/7 be modified to better manage the variability by pre-testing sites, laying fewer control paints throughout the day, and managing the seasonal effect, either by avoiding late autumn and winter application or by moderating results with respect to the performance of control paints. When using field trials for type approval, care is needed before excluding a marginal material on the basis of a single field-trial test result. Data on performance of paint in normal use could also be used to supplement data from the field trial.

Abstract

This project was undertaken to establish reliable test methods by which the performance of road markings in New Zealand can be assessed. These tests can then be used by roading authorities in specifying performance and by contractors and manufacturers to improve products.

Key tests used to quantify road-marking performance had been giving uncertain results. Measurement of reflectivity needed to be made more consistent and limits of precision established. A reliable laboratory-based skid test for paints was needed to enable product development. The consistency of field trial testing needed to be established so that manufacturers could systematically improve both the performance and cost-effectiveness of their products. The study determined the reliability of these tests and makes recommendations to improve them.

1. General Introduction

Key tests used to quantify the performance of road markings used in New Zealand give uncertain results. These uncertainties seriously impede the development of performance-based specifications and limit the improvement of delineation on New Zealand roads.

This project was undertaken between July 1999 and June 2001 to establish reliable tests by which the performance of New Zealand road markings can be assessed. These tests can then be used by roading authorities in specifying performance, and by contractors and manufacturers to improve products.

The project had three objectives:

- to establish the repeatability and reproducibility of measurements of night-time reflectivity of markings over typical New Zealand (i.e. chipseal) road surfaces,
- to determine the reliability of a laboratory test for the skid resistance of paint markings, and
- to establish the consistency of paint field trials over chipseal surfaces.

The report is in three parts, each describing one of these objectives.

Part I:

Retroreflectometer Measurements

2. Introduction

2.1 Need for Study

Tests for night-time reflectivity of road markings are well known. They involve the use of a retroreflectometer, a device which directs light onto the marking at a low angle, and records the light reflected at a similarly low angle. These angles are chosen to simulate night-time driving conditions.

Although retroreflectometers have been available for about 15 years, they are unusual in that the values obtained are specific to the type of instrument, and there is a lack of traceability to national standards. When the instruments were used as a research tool only, these factors, though of concern, were not a major difficulty. However, they are now being used as a tool by roading authorities (both Transit New Zealand and local government) when assessing the visual performance of road markings done by contractors.

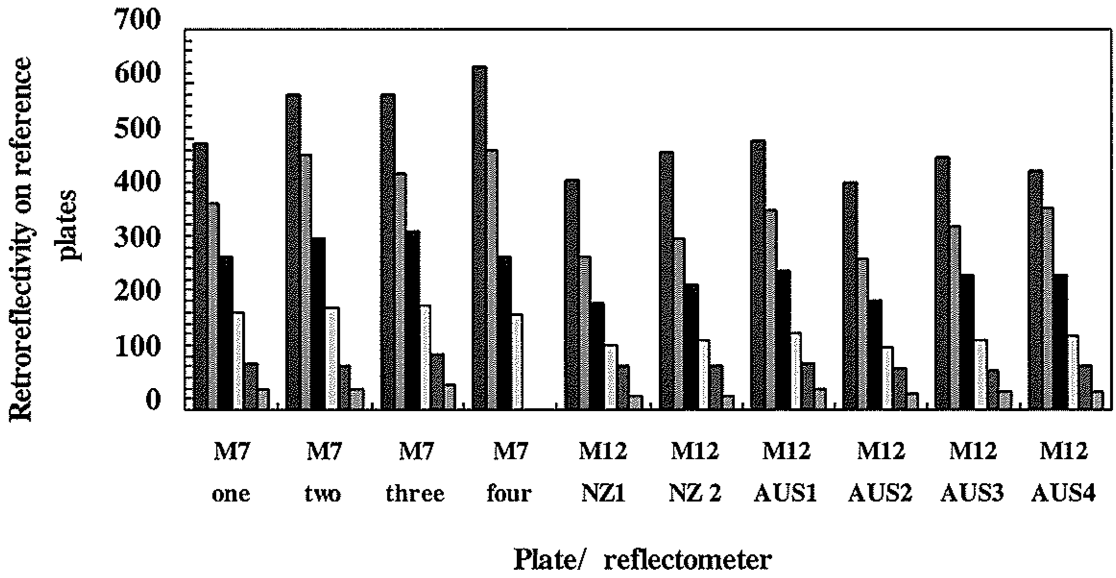
Work undertaken for Transit New Zealand has shown that readings obtained for a group of retroreflectometers can vary by an unacceptable 50–70%. It is believed that this variation could be reduced to an acceptable level by a system of calibration, traceability to national standards and more precise method of use. This improved level of accuracy would be valuable for two reasons. First, performance-based contracts are likely to be more enforceable if the test is more reliable. Second, and more important, higher levels of night-time visibility for road markings are being specified as a means of improving road safety, particularly for older drivers. The confidence provided by a reliable test of whether this performance is being delivered will be an important part of improving road safety in this way.

2.2 Variability

Retroreflectometers have been found to be variable both within brands and between instrument types. As an example, Figure 2.1 shows the results obtained by measuring on six flat reflective surfaces over the range of retroreflectivity values usually encountered with road markings. The measurements have been made with Mirolux 7 and Mirolux 12 units, which have the same illuminations and observation angles, but different light sources. The Mirolux 12 uses an incandescent bulb, and the Mirolux 7 red light-emitting diodes.

Although the results are variable, they are also systematic. Mirolux 7 readings tend to be 30–60% higher than Mirolux 12 readings. Each instrument provides the same rankings for the retroreflectivities of the surfaces.

Figure 2.1 Variability of retroreflectometers (Mirolux 7 and 12 units) on six different reflective markings on flat surfaces.

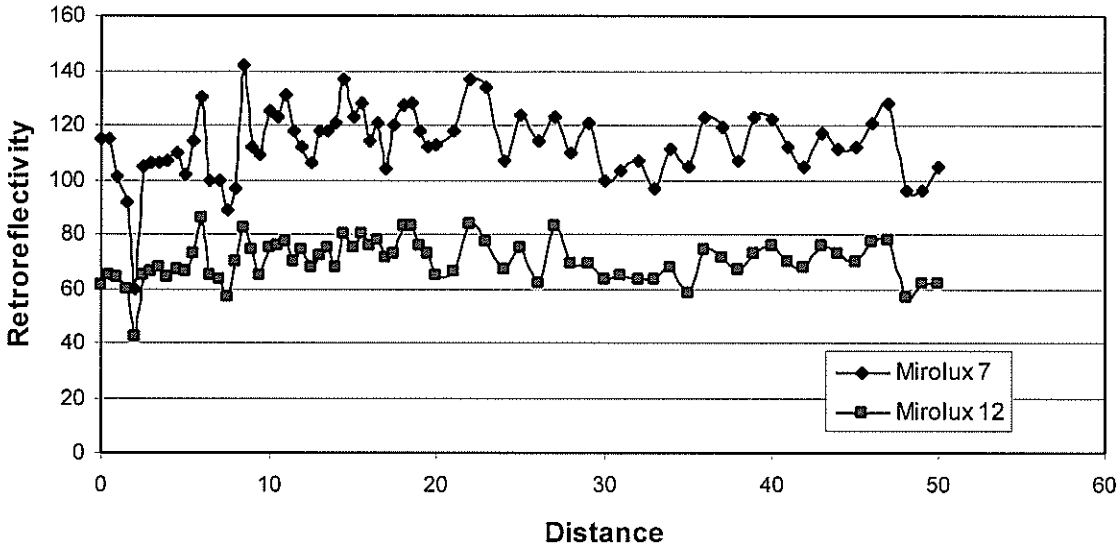


Calibration of the instruments against recognised national standards would be the normal way to resolve this variability. However, at the start of this project in 1999 no system was suitable. Transport South Australia has subsequently undertaken work to establish a calibration system, and it is believed that this will be available by the end of 2001. The method of standardisation outlined in Section 2.3 has been developed as an interim measure until a calibration system accessible to New Zealand users is available. This method allows retroreflectometer readings to be corrected to a common base. It also provides a way of adjusting readings to the "level of brightness" that has been agreed for New Zealand.

Retroreflectivity along the road varies too, especially on chipseal surfaces. This variability is illustrated in Figure 2.2, where readings have been made first at 200 mm intervals, then at 500 mm intervals, along a short section (20 metres) of road marking. This variability arises for several reasons. As well as the variation between retroreflectometers, already discussed, road surfaces are highly irregular at the micro level. Aggregate used in roading is typically 5–20mm in size and is manufactured to have many broken faces. These chip faces and voids present a highly variable reflective surface to the retroreflectometer, so that retroreflectivity can be significantly different over 5–20mm intervals. The marking can also be worn differentially along its length by the traffic so that, at intervals of 100 to 200 metres, the marking will show different levels of retroreflectivity because of the loss of both paint and reflective beads.

This project therefore sought first to develop a method of resolving the variability of the instruments, then to apply the instruments to road markings so as to evaluate the repeatability and reproducibility of retroreflectometer measurements in on-road conditions.

Figure 2.2 Variation of on-road retroreflectometer measurements with distance and between two retroreflectometers.



2.3 Common Reference for Retroreflectometers

In 1993, a working party which was part of a Transit New Zealand research project established that New Zealand road markings should have a minimum level of reflectivity of 100 mCd.m^{-2}.Lux^{-1} (Dravitzki & Potter 1993). At the same time, readings were taken on four retroreflective plates with retroreflectivities straddling the range provided by most markings. The numbers obtained when those plates were measured with the Transit New Zealand retroreflectometer at that time can be used as a baseline to serve as a common reference for retroreflectometers. The marking that was considered to have a minimum desirable level of brightness was measured for retroreflectivity with a Mirolux 12 unit. It was found to have a retroreflectivity close to 100 mCd.m^{-2}.Lux^{-1}, and this was taken as the minimum level.

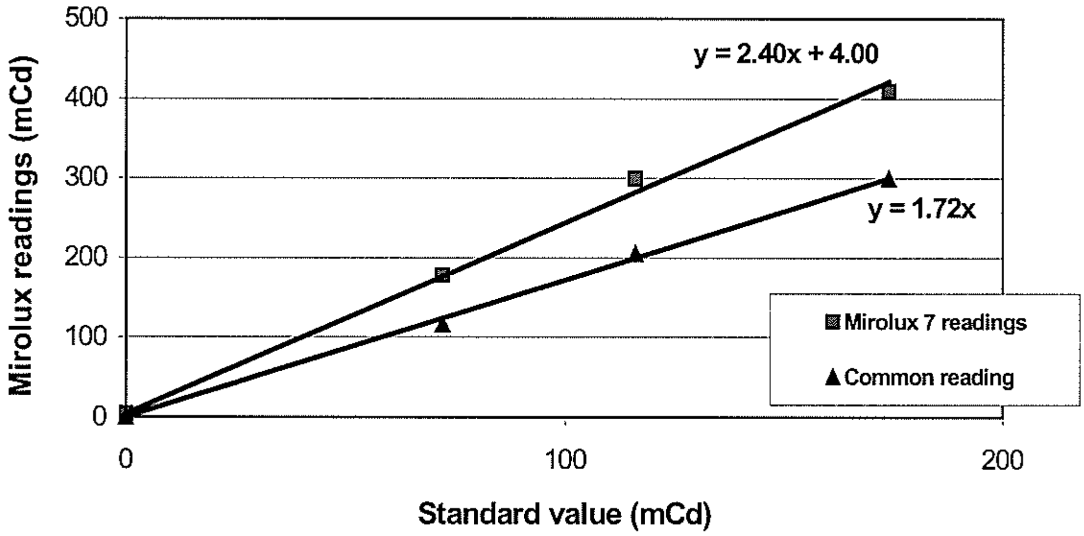
By measuring on the same plates with other instruments, conversions to the common reference can be developed. This process could also be applied to the Transit New Zealand retroreflectometer, so its current readings could be adjusted to the readings made earlier.

This common reference is valid even when the calibration system being developed by Transport South Australia is completed. While that may change the values assigned to the reflective plates, what does not change is the level of "marking brightness" to which a value of 100 mCd.m^{-2}.Lux^{-1} was assigned as measured by a Mirolux 12 in 1993. The readings taken on those plates act as a record of the brightness agreed upon. If the calibration system showed that this number should be 130, for example, then the requirement would be adjusted to this level.

Care is needed, however, if a retroreflectometer with another geometry is used. Retroreflectometers with different geometries are still likely to give a consistent relationship to the reference plates on smooth surfaces. On chipseals, however, the higher-angled instrument will see into the voids more than the lower-geometry instrument, giving an inconsistent relationship.

Figure 2.3 gives an example of using this common reference. The baseline is linear over the main range but tends to become non-linear at high values. For most values the equation of the line is Y = MX+C. It is zero on the black plate.

Figure 2.3 Converting retroreflectometer readings to a common reference.



The reading on the reference plates with Retroreflectometer 1 is:

Reading 1 = (Slope of line 1) x (nominal reading on reference plate)

The reading with Retroreflectometer 2, where the black reading does not equal zero, is:

Reading 2 = (slope of line 2) x (nominal reading on reference plate) + (reading on black plate)

These can be rearranged so that the nominal reading on the reference plate drops out.

$$\text{Reading } 1 = \frac{\text{Reading } (2) - \text{black plate reading } (2) \text{ x slope of line } 1}{\text{Slope of line } 2}$$

$$= (\text{Reading } 2 - 4) \text{ x } \frac{2.4}{1.7}$$

Using this formula, any reading made by Retroreflectometer 2 can be converted as if it was made using Retroreflectometer 1.

2.3.1 Normalising Results to the TNZ Mirolux 12 Readings

Using this process, regression formulas on the four reference plates were determined for a group of retroreflectometers to be used in the repeatability trial, as shown in Table 2.1. The formula above could then be used to convert the results.

Table 2.1 Summary of regression analysis.

Reflectometer	Regression formula on reference plates	Formulas to standardise to common reference
1. Mirolux 12	1.72 x	N/A
2. Mirolux 12	-15 + 1.76 x	0.98 (x -15)
3. Mirolux 7	3.28 x	0.52 x
4. Mirolux 7	2.71 x	0.63 x
5. Mirolux 7	2.51 x	0.69 x
6. Mirolux 7	2.44 x	0.70 x
7. MX 30	2.66 x	0.65 x
8. MX 30	1.57 x	1.10 x

Tables 2.2, 2.3 and 2.4 appear on page 20. Table 2.2 shows the raw retroreflectivity readings obtained when measuring the common reference plates. Table 2.3 shows these raw values converted to the common reference using the equations from Table 2.1. Table 2.4 gives a brief analysis of these readings by retroreflectometer type.

Tables 2.3 and 2.4 demonstrate that the use of the reference surfaces had greatly reduced the variability of the readings of the retroreflectometers. As shown in Table 2.4 there was still some variation. With the two Mirolux 12 units, much of the variation came from one unit being offset from zero at that time, though it normally records zero. With the Mirolux 7 units, the variation arose from the units tending to be a little non-linear at higher values. For the MX 30 units, there was a wide variation. The causes were not apparent at the time of the experimental work, but are now better understood. About six months after the experimental work, it was found that one of the MX 30 units was not properly adjusted. Now that it is in the correct adjustment, a very close agreement has been found between three MX 30 units. In addition, it has been found that the MX 30 units are not linear and give readings relative to the Mirolux 12 unit on reference plates of the form shown in Figure 2.4 on page 20.

Table 2.2 Retroreflectometer readings on reference plates (raw values).

Plate no	Reference value	Retroreflectometer							
		Mirolux 12		Mirolux 7				MX 30	
		1	2	3	4	5	6	7	8
1	115	115	120	180	180	185	170	120	70
2	205	205	198	360	330	320	290	310	130
3	290	290	290	610	465	420	430	490	300

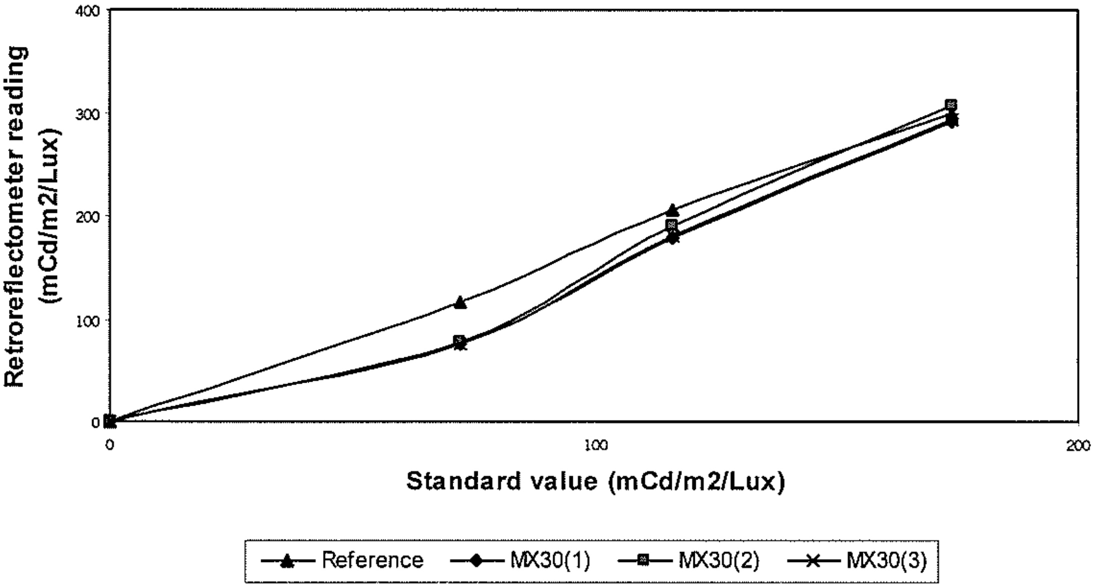
Table 2.3 Adjusted values of retroreflectometer readings on plates.

Plate no	Reference value	Retroreflectometer							
		Mirolux 12		Mirolux 7				MX 30	
		1	2	3	4	5	6	7	8
1	115	115	103	94	113	127	119	78	78
2	205	205	179	187	207	220	203	201	128
3	290	290	269	317	292	289	301	318	190

Table 2.4 Mean values of retroreflectometer types ($mCd.m^{-2}.Lux^{-1}$).

Plate no	Reference value	Mirolux 12		Mirolux 7		MX 30	
		Mean	Std dev.	Mean	Std dev.	Mean	Std dev.
1	115	109	6	113	12	78	-
2	205	192	13	204	12	164	36
3	290	280	10	299	11	254	64

Figure 2.4 Readings of three MX 30 retroreflectometers.



3. Repeatability and Reproducibility Study

A study was then done to establish the repeatability and reproducibility of the retroreflectometer as used in New Zealand when measuring typical road markings.

3.1 Experimental Design

Eight retroreflectometers were used in the trial:

- two Mirolux 12s,
- four Mirolux 7s, and
- two MX 30s.

Each of these units was used by the road marking contractor or the laboratory which normally operated it. No additional training was given to the operators in the use of the instruments other than to explain the tasks required of them in these trials.

Each of the units was used to make 20 measurements at approximately 1 metre intervals on each of 12 paint lines. The lines were spread over six sites, representing a range of chipseal surfaces and paint conditions, as shown in Table 3.1.

Table 3.1 Experimental design of retroreflectivity tests.

Code	Site	Surface type	Paint type	Paint condition
A	Harcourt Werry Drive	Grade 3	Paint	New
B		Grade 3	Paint	Good
C		Grade 3	Paint	Worn
D	Marie Street	Grade 6	Paint	Worn
E		Grade 6	Paint	New
F	Brook Street	Asphalt	Paint	Worn
G	Heath Grove	Grade 5/6	Paint	Good
H		Grade 5/6	Paint	Excellent
I		Asphalt	Thermoplastic	Excellent
J	Bell Road	Grade 4	Paint	Good
K	Placemakers Yard	Asphalt	Thermoplastic	Excellent
L		Asphalt	Thermoplastic	Excellent

3.2 Retroreflectivity Results

Table 3.2 shows the mean of the 20 readings at each site for each retroreflectometer, and Table 3.3 shows these readings converted to the common reference.

Table 3.2 Round robin, average reflectivity (20 readings per site).

	A	B	C	D	E	F	G	H	I	J	K	L
1. Mirolux 12		65	27	30	231	48	66	142	312	72		
1. Mirolux 12 (16 & 17/11)	182	97	63	53	223	65	80	145	317	83	144	232
2. Mirolux 12	94	46	25	36	214	56	68	139	304	79		
3. Mirolux 7	247	193	70	58	302	102	110	238	417	130		
4. Mirolux 7	211	128	62	78	407	119	129	264	534	159		
5. Mirolux 7	205	103	52	64	329	99	116	244	463	138		
6. Mirolux 7	247	150	61	53	310	97	113	227	429	122		
7. MX 30	85	53	27	30	200	46						
7. MX 30 (16 & 17/11)	132	69	46	35	182	46	53	148	315	52	150	168
8. MX 30	106	79	56	42	218	53						
8. MX 30 (16 & 17/11)	122	71	44	33	179	44	53	145	321	54	147	167

Note: A, B and C on 11/11/99 were all recorded when water may have been present. When recorded on 16/11/99 & 17/11/99 they were dry.

Table 3.3 Adjusted readings using common reference formula.

	A	B	C	D	E	F	G	H	I	J	K	L
1. Mirolux 12		77	40	43	235	60	77	150	312	83		
1. Mirolux 12 (16 & 17/11)	180	95	61	51	221	63	78	143	315	81	142	230
2. Mirolux 12	97	51	32	42	212	61	72	140	298	83		
3. Mirolux 7	177	138	50	41	217	73	79	171	299	93		
4. Mirolux 7	134	81	39	50	259	75	82	168	340	101		
5. Mirolux 7	107	54	27	34	172	52	61	127	241	72		
6. Mirolux 7	170	103	42	36	213	66	78	156	295	84		
7. MX 30	54	34	17	19	127	29						
7. MX 30 (16 & 17/11)	189	99	67	50	261	65	75.967	212	452	75	215	241
8. MX 30	114	85	60	45	234	57						
8. MX 30 (16 & 17/11)	131	76	48	35	192	47	57	155	345	58	158	180

3.3 Analysis

The spread of retroreflectivity results for a site were observed to be approximately proportional to the mean of the measured retroreflectivity for that site, so the values were transformed using a natural logarithm before processing.

Since a natural logarithm analysis was used, the repeatability and reproducibility values calculated are in terms of the fraction of the mean value, effectively independent of the actual value of the reflectance. The results are therefore quoted as a percentage of the mean reflectance measured at a site.

Four types of variability were estimated, using a one-way analysis of variance (ANOVA). They were the variance due to:

- instrument (the difference between retroreflectometers),
- site (the difference between paint markings, which includes paint wear and surface type),
- site*instrument (the interaction between site and instrument variation),
- measurement error (any effects not included in this experiment, including random error).

An independent estimate of each of these variances can be obtained from the ANOVA table. The results are presented in Table 3.4, which shows that:

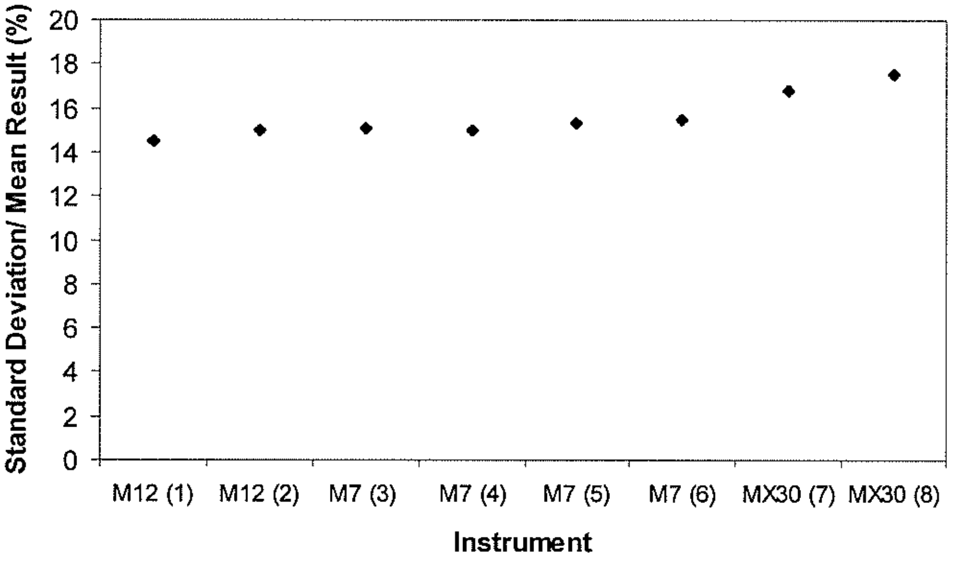
- by far the largest part of the variation is due to site,
- the residual error is larger than the variance due to instrument and site*instrument interaction.

Table 3.4 Independent estimate of variance.

	Variance	**Standard deviation, σ**
Instrument	0.015	0.124
Sites	0.540	0.735
Site*instrument interaction	0.008	0.090
Residual	0.051	0.225

Figure 3.1 on page 24 shows the standard deviation for each retroreflectometer. Although all were broadly similar, the two MX 30 instruments showed a larger variation.

Figure 3.1 Comparison of standard deviation of retroreflectometer instruments.



3.4 Estimating the Variance due to the Independent Variables

Weather affected the results on sites A–C, and sites K and L were used for only some instruments. The data set for the ANOVA was restricted to the seven sites, D–J, which were used with all the instruments. The results of the ANOVA are shown in Tables 3.5 and 3.6.

Table 3.5 Analysis of variance, main effects only ($R^2 = 0.914$).

Source	**Df**	**Σ of squares**	**Mean square**		**F value**	**Pr>F**
Instrument	7	16.575	2.368	$= V_E + 20*V_{SI} + (7*20)V_I$	48.99	0.0001
Site	6	519.571	86.595	$= V_E + 20*V_{SI} + (8*20)V_S$	1791.69	0.0001
Site*instrument	42	8.8913	0.212	$= V_E + (20)V_{SI}$	4.38	0.0001
Measurement error	1087	55.618	0.051	$= V_E$		

Table 3.6 Analysis of variance, main and second order effects only ($R^2 = 0.977$).

Source	Df	Sum of squares	Mean square	F value	Pr>F
Site	6	519.571	86.595	5141.14	0.0001
Instrument	7	16.575	2.368	140.58	0.0001
Repetition	19	4.6982	0.247	14.68	0.0001
Site*instrument	42	8.8913	0.212	12.57	0.0001
Site*repetition	114	31.0909	0.273	16.19	0.0001
Instrument*repetition	133	2.1947	0.017	0.98	0.5489
Residual error	798	13.441			

Table 3.6 shows that the three main variables of site, instrument and repetition, and the two interactions of site with instrument and site with repetition, were significant and explained most of the variability. The analysis showed that:

- Site is significant. This finding was not unexpected, as sites with a wide range of retroreflectivities were selected. However, it shows that these instruments can clearly distinguish the differences in retroreflectivities between sites.
- Instrument is significant. This term does not separate the instrument from the operator, but the combination is a significant source of variability.
- Repetition is significant – that is, the number of measurements taken from a site affects this result.
- The interaction of site with instrument is significant – that is, different sites (i.e. different surfaces) can have a significant effect on how the instrument behaves.
- The interaction of site with repetition is significant. This shows that some sites are much more variable than others, so that more readings would be needed on the more variable sites to obtain a stable mean.
- The interaction of instrument with repetition is not significant – that is, each instrument gives a similar spread of data. This could indicate that, within the site, retroreflectivity can vary significantly at the micro level.

3.5 Repeatability and Reproducibility

In the context of this report, with paint markings and climatic conditions the same, and elapsed time between readings minimised, the definition of repeatability and reproducibility is:

- Repeatability is the difference between two sets of measurements made with the same retroreflectometer at the same site.
- Reproducibility is the difference between measurements made by two different retroreflectometers at the same site.

Repeatability depends solely on the measurement variance. For a 95% confidence level, the repeatability (r) is:

$$r = 1.96 \text{ x } \sqrt{(2 \text{ x } (V_E))}$$

Reproducibility depends on the sum of the measurement and between-instrument variances. For a 95% confidence level, the reproducibility (R) is:

$$R = 1.96 \text{ x } \sqrt{(2 \text{ x } (V_1 + V_{SI} + V_E))}$$

Using the estimates of variance calculated in Section 3.3, it is now possible to estimate the repeatability and reproducibility for the paint marking trials with respect to the number of readings made at a site, as shown below in Table 3.7 (for a 95% confidence level) and Table 3.8 (for a 90% confidence level). The formulas relating repeatability and reproducibility to the number of readings (n) are:

$$r = 1.96 \text{ x } \sqrt{(2 \text{ x } (V_E / n)}$$

$$R = 1.96 \text{ x } \sqrt{(2 \text{ x } (V_1 + V_{SI} + V_E / n))}$$

The repeatability shows the consistency of the test if any one of the instruments was used to measure the retroreflectivity of the paint marking at any one of the sites. The reproducibility shows the consistency if any two instruments were used to measure any one of the markings. This consistency changed as the number of measurements was increased. Because of problems with the weather, the results from sites A–C were not used in the regression. Due to operator unfamiliarity with the MX 30 unit, which was newly available at the time of the test, this analysis was made both with and without data for the MX 30 units included.

Table 3.7 Repeatability and reproducibility as a percentage of the retroreflectivity for a 95% confidence level.

Number of readings made at a site (n)	**All instruments**		**Excluding MX 30s**	
	Repeatability	**Reproducibility**	**Repeatability**	**Reproducibility**
1	60.9%	74.3%	61.2%	69.5%
10	19.3%	46.7%	19.4%	38.1%
20	13.6%	44.7%	13.7%	35.6%
30	11.1%	44.0%	11.2%	34.7%
50	8.6%	43.4%	8.7%	34.0%
100	6.1%	43.0%	6.1%	33.6%
200	4.3%	42.8%	4.3%	33.2%
500	2.7%	42.7%	2.7%	33.0%

Reproducibility rapidly approaches a limit of about 35%, but repeatability continues to improve with the increasing number of measurements. Table 3.7 shows the same trend as Tables 2.2–2.4: that the MX 30 units have a larger variance, resulting in larger repeatability and reproducibility results.

Relaxing the confidence level to 90% improves the repeatability and reproducibility results, as given in Table 3.8, but there is a greater chance of error – that is, 1 in 10 instead of 1 in 20 for the 95% confidence level.

Table 3.8 Repeatability and reproducibility as a percentage of the retroreflectivity for a 90% confidence level.

Number of readings made at a site (n)	All instruments		Excluding MX 30s	
	Repeatability	Reproducibility	Repeatability	Reproducibility
1	51.0%	62.2%	50.6%	58.2%
10	16.1%	39.1%	16.0%	32.9%
20	11.4%	37.4%	11.3%	30.9%
30	9.3%	36.8%	9.2%	30.2%
50	7.2%	36.3%	7.1%	29.6%
100	5.1%	36.0%	5.1%	29.2%
200	3.6%	35.8%	3.6%	29.0%
500	2.3%	35.7%	2.3%	28.8%

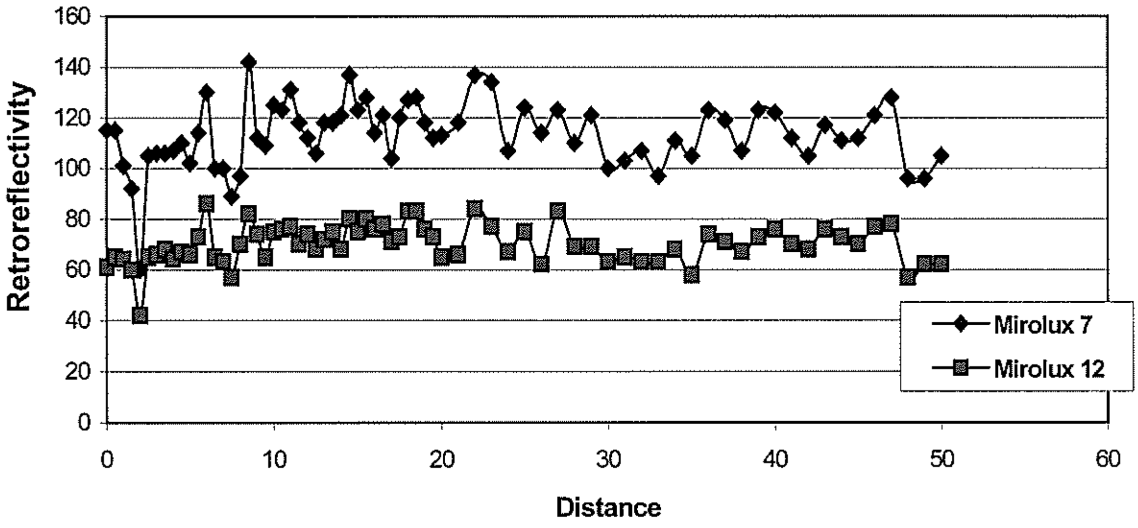
Table 3.7 shows that 20 to 30 readings are needed to give a level of repeatability which would be considered acceptable – that is, about 10%. Table 3.8 shows that reproducibility is wide, at about 31%, even when about 20 to 30 readings are taken. This range of reproducibility is too wide to be considered acceptable. For example, a badly worn marking would have a reflectivity of about 60–70 mCd.m^{-2}.Lux^{-1}, whereas a reasonable marking at the point of needing replacement has a reflectivity of about 100 mCd.m^{-2}.Lux^{-1}. This difference in reflectivity would be readily apparent, yet a 30% variance in reproducibility implies both should be acceptable.

The analysis showed that variance arose from three main factors: site, repetition and instrument, and from interactions between them (apart from the instrument/repetition factor). The reproducibilities above are for measurement at any site, so the site effect is excluded. The variation due to repetition is influenced by the high variability of retroreflectivity at the microscale along a chipseal surface. This variability is large for one or a few measurements, but, as the repeatability factors in Tables 3.7 and 3.8 show, once about 10 to 20 readings are taken, the repeatability is approaching 10% and improves only a little for 50 measurements. If a large number of readings is taken, the consistency of the test becomes very accurate.

The instrument factor is therefore a major cause of poor reproducibility. It encompasses the operators, who will have different levels of skill, different brands of instrument and different instruments of the same brand.

A better level of reproducibility had been expected. A previous exercise with laboratory personnel, who were experienced, and using two brands of instrument, obtained a very close match in the retroreflectivity of a line using the same techniques as the current trial. This is illustrated in Figure 3.2 below.

Figure 3.2 Reflectivity readings of two instruments after converting to common reference.



The fact that poor reproducibility was obtained in the current project indicates a significant variation between instruments of the same brand, and in operator skill. The latter might have been expected, as most of the operators were roading contractors who had had only limited expertise with their instruments at that time.

4. Future Use

4.1 Recent Developments

Three recent developments will favourably influence the repeatability and reproducibility of retroreflectometers. These are:

- The establishment in Adelaide, Australia, of a calibration facility for retroreflectometers which is traceable to international light standards. This will avoid the need to use the common reference plates and should greatly reduce variability between instruments.
- The industry is moving away from Mirolux 7 retroreflectometers (which are suspected of being unreliable) to the MX 30, which uses a 30-metre geometry. Now that several are available in New Zealand, it has been noted that there is a very close match of the readings of these instruments on the reference plates. Internationally, a US study (Civil Engineering Research Foundation 2001) which examined the repeatability of 30-metre geometry units cited reproducibilities on reference plates of typically 5–10%, and on road sections of typically 10%.
- The road marking industry has set up a paint-testing qualification for test personnel. Over time, members of the industry will therefore become more skilful in using paint-testing equipment, and this too will help to reduce variability.

4.2 Mobile Retroreflectometers

Mobile retroreflectometers are usually attached to the side of a vehicle and can measure the retroreflectivity of markings when the vehicle is being driven at 70–100 km/h. Although they have been available for some years, their use has increased significantly in recent times.

Mobile retroreflectometers were not part of this study, but the variability shown with the hand-held units evaluated here indicates that care will also be necessary with the mobile units. Factors creating additional uncertainty with the latter are the potential to gather spurious readings from elements such as raised pavement markers, and the change of angle as vehicles rock with road roughness and camber.

The US study (Civil Engineering Research Foundation 2001) also reviewed the repeatability of mobile instruments. As a general trend, these instruments had lower consistency than the hand-held instruments.

4.3 Conclusions

1. An interim system of resolving differences in measurements from different retroreflectometers has been established, using a set of reference plates. Currently available instruments show a wide range of raw values, but these are much more consistent when referenced to the common reference base.
2. When measuring on the road there is significant variability in the readings obtained. Statistical analysis showed that the instrument/operator combination and the variability of paint retroreflectivity at the micro level are significant sources of error.
3. Repeatability after 10–20 readings is acceptable at about 10%, and slowly becomes more accurate when many more readings are taken.
4. Reproducibility is poor, and remains at about 30% even when many readings are taken.
5. Recent changes will help to make measurements of retroreflectivity more consistent.
    - More reliable instruments are available and are being taken up by industry.
    - A calibration facility will soon be available in Australia.
    - A system of training road-marking test personnel has been established.

4.4 Recommendations

1. Care should be taken in applying retroreflectivity data from different instruments, as the tests show a level of reproducibility which is unacceptable.
2. Within performance contracts, practices such as agreeing on the test equipment to be used in assessing retroreflectivity at an early stage, and making a joint comparison of the instruments so as to agree on tolerances, should be encouraged.
3. Moves to establish and utilise a calibration facility for retroreflectometers, to equip the road-marking industry with more reliable equipment, and to provide training and qualifications for road-marking test personnel, should be encouraged and advanced as quickly as practicable.
4. A further study of the repeatability and reproducibility of retroreflectivity measurements should be undertaken after the improvements described in Recommendation 3 above have taken effect.
5. Although this study did not include mobile retroreflectometers, the variability shown by the hand-held units evaluated here indicates that care will be needed with mobile units to establish their reliability, as additional factors with these will cause greater variability of measurement.

Part II:

Laboratory Skid Resistance Test for Paints

5. Introduction

5.1 Need for Study

Typically, most road-marking paints have a much lower skid resistance than the road surface over which they are placed. They may cause a significant hazard where the markings are in the travelled area. The road surface macrotexture also has an influence, so that the hazard appears to be worse for markings over smooth surfaces or where markings are very thick as a result of multiple applications.

Manufacturers can formulate their products to improve skid resistance but lack a laboratory-based test by which to systematically develop their products. An interim laboratory-based test has been developed, in which the skid resistance of the paint on a metal plate is measured with the British Pendulum Tester. This test is included in the Transit New Zealand Specification TNZ M/7, which is used to approve types of paint for use on national highways. However, there is a lack of knowledge about:

- the consistency in this test of paint products when applied at different times,
- how the performance of products in this test translates into on-road performance, particularly in situations that may be hazardous, such as on low-texture surfaces.

This knowledge, together with a reliable test, is needed by roading authorities for specifying markings that minimise the skidding hazard, and by manufacturers for the systematic improvement of their products.

Part II of this project was therefore to establish the relevance of testing the skid resistance of a paint on a metal plate compared with the skid resistance of the same paint on a road surface. As noted above, paint films will be strongly influenced by the texture of the road. However, re-marks are often made over several previous layers of paint which, coupled with low-texture surfaces such as asphaltic concrete or partially flushed chipseal, may isolate most of the influence of the road surface on skid resistance.

5.2 Methodology of Study

In the interim test for the skid resistance of road-marking paint, a metal plate, approximately 150 x 150 mm, is placed on the road surface as the test line is applied. (This is a common way of sampling paint lines to obtain the film thickness of the applied paint.) This paint is then dried overnight in a warm (50°C) oven. After cooling, the paint film thickness (if required) is measured first, and then the skid resistance, either immediately or some days later. When the test lines are being applied, usually three plates of unbeaded paint are obtained, two plates from one line and one from the duplicate line laid.

In Part III of this project, which was to establish the reliability of the paint field trial and is described later in this report, three paint types were used to lay a series of test lines at three trial sites. These paints comprised a waterborne acrylic, a chlorinated rubber and an alkyd paint, representing the three main paint types used to mark New Zealand roads. These paints were laid in the morning and afternoon of a day in summer, autumn, winter and spring, and were also applied on the day following each of these four days.

These test lines therefore provided a suitable source of test plates of several paint types, applied many times over a range of environmental conditions. A selection of these test plates, comprising morning and afternoon applications in summer and morning applications in the other three seasons, was made and tested for skid resistance with the British Pendulum Tester, using the test methodology of Road Note 27 but with appropriate minor modifications for testing paint over a metal plate. The three plates taken for each pair of test lines were tested, then averaged, to obtain a single value for that pair of test lines.

To identify the relationship between the skid resistance of the paint on test plates and that on the road, skid tests were made on road sections painted with the paints used in the field trials in Part III of this project. The road sections selected included:

- asphalt with moderate and heavy residual previous layers of paint,
- heavy residual layers of paint over grade 4/5 chip,
- moderate residual layers of paint over grade 3 chip,
- previously unpainted grade 3 chip.

6. Analysis of Results

6.1 Test Plate Results

The skid resistance of the test plates taken from the paint field trials, as measured by the British Pendulum Tester (BPT), is shown in Table 6.1. The results are given in British Pendulum Numbers (BPN). Each skid test result is the average of the three test plates taken for that line.

Table 6.1 Statistics of skid tests made on paint samples used in field trials, measured in BPN.

	Paint type		
	Waterborne acrylic	**Chlorinated rubber**	**Alkyd**
Size of sample	36	30	36
Mean	30.1	15.3	36.5
Standard error of mean	0.5	0.4	0.4
Standard deviation	3.2	2.1	2.7
Variance	10.2	4.5	7.2
Range	12	9	11

Table 6.1 shows that each of the paint types had a narrowly defined mean, and that the distribution of the test values about that mean was similar: standard deviations, standard errors and range were all similar. The 95% confidence interval of this test about the mean is ± 6.2 BPN for the acrylic, ± 4.2 BPN for the chlorinated rubber and ± 5.2 BPN for the alkyd paint.

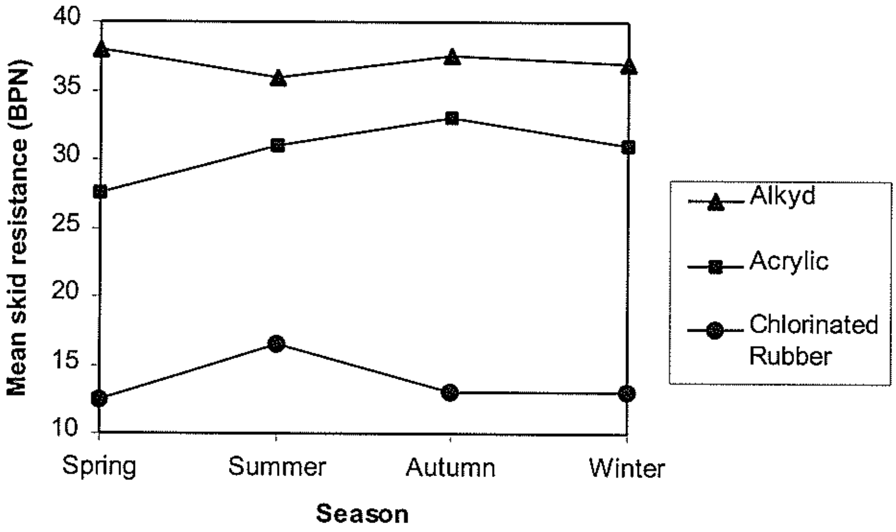
At present TNZ M/7 sets out a minimum of 30 BPN as the requirement for this test. However, the above data show that the variability is typically ± 5 BPN. If only a single sample was taken, it would therefore be required to have a value of 40 BPN or more for there to be a 95% level of confidence of its being greater than 30 BPN. However, a single sample gives little information of the variability of the candidate paint and a limit of 40 BPN may exclude many complying paints. A larger sample is desirable, but, as the sample is usually taken from test lines laid in a trial, a very large sample would also be difficult to obtain.

A sample of three is about the maximum practicable to obtain in a field trial. However, with a sample of three the mean is less certain. Using a Students T test it can be calculated that, if the target mean is set as 36 BPN, there is a 95% level of confidence that a three-sample mean of 31 BPN is statistically different. A mean of

32 BPN should therefore be accepted, although with additional samples the mean should progress towards the target mean of 36 BPN or greater.

The tests also found that skid resistance overall was not affected by the season in which the paint was laid. However, there was a slight indicative trend for the skid resistance of specific paint types to be affected by the season of application, as shown in Figure 6.1.

Figure 6.1 Skid resistance by paint type and season of application.



6.2 Relating Laboratory Skid Test to On-road Values

The next phase was to establish the relevance of testing the skid resistance of paint applied over a metal plate compared with that applied over a road surface. It was expected that the road surface would influence the skid resistance of the painted road, but that this influence would lessen both when the road was of lower surface texture and when the paint layers from previous applications were thick.

A wide range of road surface types are modified both by trafficking and by previous paint regimes, so determining rigorous correlations would have been very difficult. However, tests of the paints used in the field trials over a selection of road surfaces and previous paintings provide a good indication of the correlation.

The paints used in the field trial were also applied to previously painted asphaltic concrete, grade 4/5 chipseal, grade 3 chipseal and previously unpainted grade 3 chipseal. The skid resistance of the painted lines was measured with the BPT following the procedures of Road Note 27. The results, measured in BPN, are shown in Tables 6.2 to 6.5.

Table 6.2 Skid resistance in BPN over asphalt (skid resistance of road, 73 BPN).

Paint type	Painting over		
	Thin paint	Thick paint	Bare road
Acrylic	40, 40 40, 40	40	
Alkyd	43, 43	52, 40 43, 41, 42	53, 54

Table 6.3 Skid resistance in BPN over grade 4/5 chipseal (skid resistance of road, 70 BPN).

Paint type	Painting over	
	Thin paint	Thick paint
Acrylic	45, 42	
Alkyd	46, 49	44, 46 35, 33 (very thick)

Table 6.4 Skid resistance in BPN over grade 3 chipseal (skid resistance of road, 85–94 BPN).

Paint type	Painting over light paint
Alkyd	65, 64 76, 72

Table 6.5 Skid resistance in BPN over grade 3 chipseal (skid resistance of road, 86 BPN).

Paint type	Beaded	Unbeaded
Acrylic	66, 65 60, 62	42, 40 46, 43
Chlorinated rubber	55, 58 31, 55	33, 31 34, 40
Alkyd	75, 76 75, 75	63, 59 48, 60

These tests show that:

- A single application of paint on a previously unpainted road will usually significantly reduce the skid resistance. A reduction of 20–50 BPN can occur, and the extent of the reduction corresponds to the skid resistance of the paint as measured over the metal plate. The skid resistance of the newly painted road is greater than that of the paint over the metal plate.
- On low-texture surfaces (e.g. asphalt and grade 4/5 chipseal) painting over existing paint, whether thick or thin, appears to give a painted line with a skid resistance only slightly higher (5–10 BPN) than that obtained for the paint over the plate.
- The addition of glass beads for reflectorisation appears to significantly increase the skid resistance of the painted line (by 15–20 BPN).

Transit New Zealand (Transit) has recently amended its specifications so as to require the skid resistance of its painted road markings to be 45 BPN or greater. This requirement is pertinent when considering the relevance of the skid test of paint applied over a metal plate as part of the approval process for paint types.

Chlorinated rubber paint rated low (15 BPN) in this test and, even in the very favourable situation of being painted over a bare, highly textured road, its skid resistance is low. Waterborne acrylic and alkyd paints gave moderate results (30 and 35 BPN) in this test, and they also give only moderate skid resistance when applied over existing markings or low-textured roads. The slightly higher skid resistance of the alkyd paint in this test is reflected in the on-road results.

Transit currently requires a minimum value of 30 BPN in the interim laboratory-based skid resistance test. The present trial shows that a higher pass value is needed if the on-road value of 45 BPN or higher is to be obtained with any certainty. This trial indicates that there is only a very small increase in skid resistance on the painted road compared with the painted metal plate. To be certain of obtaining 45 BPN on the road, the laboratory test pass value needs to be increased to 40–45 BPN. Achieving this higher skid resistance on the metal plate may be difficult for paint manufacturers, as harsher fillers may abrade and wear equipment, for example, or other paint properties may change. The industry would need to be consulted if the laboratory-based skid resistance requirement was to be increased.

There are alternative ways to enhance skid resistance. A fine aggregate material or glass beads could be added to the paint. Glass beads, when added to the surface to provide retroreflectivity, also help to increase skid resistance. The duration of the effect depends both on how long the grit or beads are retained within the surface and on the nature of the surface once the grit or beads are removed. There is some experience to show that, where glass beads have been removed from a paint surface, a texture of little craters has been created, making the skid resistance still acceptable.

7. Conclusions and Recommendations

7.1 Conclusions

1. The method of defining the initial skid resistance of a painted line by measuring the skid resistance of a film of the paint sprayed over a metal plate has been found to be variable within a typical confidence interval of ± 5 BPN.
2. A larger sample of painted plates is necessary. Three samples each of three painted plates are needed adequately to sample the paint for this test.
3. If confidence is required that almost all paint (95%) will pass a required value such as 30 BPN, then the target mean needs to be increased by half of the confidence interval.
4. A revised pass value of 36 BPN based on the mean of three samples is recommended.
5. This skid test correlates to on-road values. New markings laid over previously painted markings on low- to medium-textured road surfaces have skid resistance values similar to, but a little higher than, values obtained on the metal plate.
6. Paint with skid resistance values of between 30 and 36 BPN on the metal plate can often have skid resistance values less than 45 BPN on previously painted surfaces. 45 BPN is now the minimum accepted value in Transit New Zealand specifications.
7. If 45 BPN is to be attained with certainty on the road, then either the skid resistance of paint films as determined by this test needs to be increased to about this value, or alternatively skid-reducing materials need to be added to the paint on application.

7.2 Recommendations

The following recommendations are based on the experimental work and analysis done in this part of the project.

1. The test for the skid resistance of a paint type described in TNZ M/7, whereby skid resistance is determined as the BPN of a film of that paint sprayed over a metal plate, should be retained but with the following modifications.
    - The sample size should be increased from a single plate to three samples each of three plates.
    - The pass value in the specifications should be adjusted to allow for the significant variability of the test, so as to give a 95% confidence level of ± 5 BPN.

2. Consideration should be given to increasing the pass value so as to be more certain that the desired on-road skid resistance values specified in TNZ P/20 and P/12 of greater than 45 BPN are attained.
3. Alternatively, consideration should be given to amending the paint specification so that additives that enhance skid resistance, such as retroreflective glass beads or an abrasive material such as crushed silica, or a combination of the two, can be added to painted markings to ensure that the specified skid resistance values are attained.

Part III:

Paint Field Trials

8. Introduction

8.1 Need for Study

Field trials are used in many countries as a primary means for manufacturers to demonstrate to the industry and roading authorities that their products are of an acceptable standard, and for roading authorities to select suitable products. New Zealand has differed from other countries in that these trials are carried out on chipseal, which is the dominant road surface. Practices in Australia are now changing. Testing on chipseal surfaces is now used also in South Australia. The current test procedures in the joint AS/NZS4049:1992 series for road-marking materials are being reviewed, and the latest draft includes testing over chipseal, asphalt and concrete where these surfaces are normally applicable.

Since 1993, Opus Central Laboratories has been carrying out field trials for the industry to appraise its performance in relation to the requirements of TNZ M/7. Both Opus's and the industry's experience with this specification has raised concerns about the consistency of this test with respect to:

- similar results from successive tests,
- tests at different locations,
- tests at different times of the year,
- varying application methods and equipment.

Some of these inconsistencies are believed to be caused by the chipseal surface, which is acknowledged to be a less consistent and harsher surface than the dense asphalt used in other countries. However, the use of chipseal needs to be continued as it is New Zealand's dominant surface, and paint wear on chipseal is significantly different from that on asphalt.

The variability has been minimised so far by the current M/7 approval system, whereby Transit requires that all paints be tested concurrently in a single large trial. Progressive product development by manufacturers, however, means that they have to test their products outside the approval cycles arranged by Transit. The changing industry environment is now such that manufacturers need on-road test information to provide to re-marking contractors undertaking performance-based contracts.

There is also a need for product improvement. New Zealand chipseals are a harsh environment for road markings and it appears that current paint systems have difficulty in achieving even the minimum levels of performance expected in other countries. Manufacturers have made improvements recently but would like to continue to develop their products. They need reliable tests to enable a systematic approach.

8.2 Experimental Design

The experiment was designed to develop an understanding of how issues that arise during field trials may cause variability in the results. These are discussed below.

8.2.1 Site

Unlike several other countries, New Zealand does not have a fixed site for all road trials of marking materials. Different sites are used from time to time and are selected on the basis that they fulfil the traffic volume, speed and road type requirements of TNZ M/7. While it is known that the type of road surface can affect performance – for example, paints can perform markedly differently on chipseal compared with asphalt – there was uncertainty as to whether the limitations on the site as described in TNZ M/7 were sufficient to ensure that a consistent performance would occur, either from one site to another, or at the same site at one point in time compared with several years later.

Three sites were used in the experiment, all in the Wellington/Wairarapa area. The type of aggregate, e.g. greywacke, was similar but the source varied, giving some differences in mineralogy. If these sites showed variation, then a greater variation could be expected throughout the country, where aggregates have a much greater mineralogy range.

8.2.2 Season

At present, trials of paint materials can begin at any time of the year, though most group trials begin in summer. However, manufacturers can develop new materials at any time and seek approval for them. Since testing usually takes from four to seven months, it is desirable that trials can begin at any season of the year.

In this experiment, trial materials were laid in summer (December), autumn (late March), winter (July) and spring (October).

8.2.3 Time of Day

Usually several materials are to be laid in any one day. Some will be laid in the morning and some in the afternoon. The last material is laid no later than two hours before the road is opened for traffic. Some materials will therefore have been laid for six to seven hours before trafficking, others only two hours. At issue was whether this time difference before trafficking (which is difficult to avoid) results in a more favourable result for materials laid early in the day compared with those laid later.

In this experiment, material was laid in the morning and in the afternoon of the same day.

8.2.4 Day-to-day Variation

Often, not all trial materials can be applied in one day. At issue was whether material laid on one day would show the same level of performance if it was laid on another day – for example, the next day.

In this experiment, identical paints were laid on successive days.

8.2.5 Paint Film Thickness

It is believed that paint film thickness can have a significant effect on paint performance, in particular on retention of retroreflective properties. Considerable effort is expended in trials to lay lines within ± 15 µm of the specified thickness, which is difficult to achieve given the very short run of material to give a transverse line (3–4 metres long). Manufacturers also incur considerable expense in testing at two thicknesses.

In this experiment, lines were laid so as to have a mean paint film thickness of either 180 µm or 250 µm.

8.2.6 Paint Type

Different types of paint are known to have different levels of performance. This experiment investigated the extent to which parameters such as season, time of day, paint film thickness and painting on successive days affect paint performance. Different paint types may also show different levels of response to these parameters.

Three paint types were used in this trial. Waterborne acrylic paint was made up to a formulation provided by the supplier of the raw material. Chlorinated rubber and alkyd paints were purchased from a manufacturer. These last two paints had been trialled previously by the manufacturer and had passed the TNZ M/7 type approval requirements.

8.2.7 Applicator

To test whether the field trials were sensitive to the paint applicator used, two paint contractors were included in this experiment.

8.3 Experimental Method

In common with most paint trials, trafficking was taken as the factor causing paint deterioration (though environmental degradation can be more significant for paints lasting one year or more). Lines were laid across the lane so that each vehicle using that lane would cross the test lines. Each vehicle crossing is described as a vehicle pass (no allowance is made for the additional axles of heavy traffic). Paint performance was monitored at 330,000, 660,000 and 1 million vehicle passes, and thereafter in approximately 500,000 increments, up to 2 million for many of the test lines but up to 4 million for a few lines.

Paint markings were laid at the test sites in December 1999, March 2000, July 2000 and October 2000 in conditions satisfying as far as possible those of TNZ M/7. These times were taken to equate to summer, autumn, winter and spring conditions.

Lines were laid transversely across the road. Two reflectorised lines using standard drop-on glass beads complying with AS/NZS2009:2000 at the rate of 275 gm/m^2 were always laid. In addition, one and usually two unbeaded lines were laid of each paint and film thickness. The thickness of these unbeaded lines was taken as representing the thickness of the reflectorised lines.

Paint application in the morning started between 9.00 and 10.00 am. Afternoon applications started about 1.00 pm. Two hours were allowed before the road was open to trafficking, usually at about 4.00 pm.

Marking performance was assessed for wear (paint loss) and retroreflectivity (brightness). These tests were the same as those specified in TNZ M/7.

Wear was assessed against a photographic scale of 0 to 10, where 10 equates to no paint loss and 0 to paint remaining in the chip voids only. Usually 4 equates to satisfactory performance. This photographic scale was developed by the Laboratoire Central des Ponts et Chaussées (LCPC) in France but it is used in New Zealand as part of TNZ M/7. The scale is non-linear, so the first three steps (7, 8 and 9) correspond to the loss of very small sections of paint.

Retroreflectivity was measured in two positions: the left wheel path (LWP) and the less trafficked area between the wheel paths (BWP). Five readings were taken on the LWP, three on the BWP. Retroreflectivity was typically 220–250 mCd.m^{-2}.Lux^{-1} for newly laid material measured after the first 24 hours of trafficking. On heavily degraded lines retroreflectivity is typically 50–60 mCd.m^{-2}.Lux^{-1}. Once degraded, and after about 1.5 million vehicle passes, many of the lines were removed so that either new lines could be added to the site or the road restored to its previous unmarked condition.

The sites used were:

- State Highway 2 (SH2) in Upper Hutt, about 500 metres north of the Moonshine Bridge, a 100 km/h area,
- Harcourt Werry Drive, about 500 metres south of the Kennedy-Good Bridge, a 70 km/h area, and
- SH2 about 1 km south of the Waingawa River, Masterton, a 100 km/h area.

Traffic volumes were 8000 vehicles per day at the Moonshine site, and about 4000 vehicles per day at the other two sites.

A summer application of material was made at the Masterton site (December 1999) and the initial assessment of line condition after about 300,000 vehicle passes. However, in March and April 2000 road works associated with installing passing lanes about 2 km to the south began. Dirt was tracked along the road and across the site. This appeared to degrade the markings, but it is also thought to have contaminated the site. The autumn application failed prematurely even though the road appeared reasonably clean. For the winter application some areas were water-blasted, but this gave no improvement in reducing the premature failure of the markings applied over the water-blasted areas. Therefore the Masterton site was excluded from subsequent work.

9. Analysis of results

The analysis of variability focused on line condition after about 1 million vehicle passes. This number of passes was experienced by all of the lines and corresponds to the main extent of trafficking used when assessing marking performance in paint trials.

Data included were the observations from two sites recorded around the 1 millionth vehicle pass (the Masterton site was excluded because of degradation). Variables were entered into a factorial ANOVA with paint type to assess the influence of any factors on the mean rates of wear and LWP and BWP retroreflectivity. Post-hoc testing included an assessment of the heterogeneity of variance and was performed using either Scheffe Tests or Tamhane T2 with an error rate of 5% (p.05). Means are given for a 95% confidence level.

The main factors examined were variations in wear and variations in retroreflectivity. The first analysis was made in relation to paint type. The subsequent analysis was of the factors varied within the trial, to identify their influence on the variability. These factors were:

- site,
- seasonal effects,
- application at different times of day,
- application on different days,
- paint thickness.

9.1 Paint Type

The study showed that there was both a consistent difference in the performance of the three paints in the trial, as expected, and a variation in the performance of each paint type as a result of the factors varied within the trial.

Table 9.1 shows that the extent of variability is substantial. For example, for chlorinated rubber, the mean wear is 6 but the expected 95% confidence interval of about 4 to 8 shows a range of performance from a slight paint loss (8) through to significant paint loss (4), which is at the border of acceptability. Similarly, the mean LWP retroreflectivity is 144 $mCd.m^{-2}.Lux^{-1}$, but the expected range (for a 95% confidence level) is from about 90 $mCd.m^{-2}.Lux^{-1}$, which equates to a well-worn line needing replacement, to 200, which is near-new condition.

The analysis does show, however, that, even with this substantial range in paint performance, the field trial is sufficiently consistent to identify differences in performance.

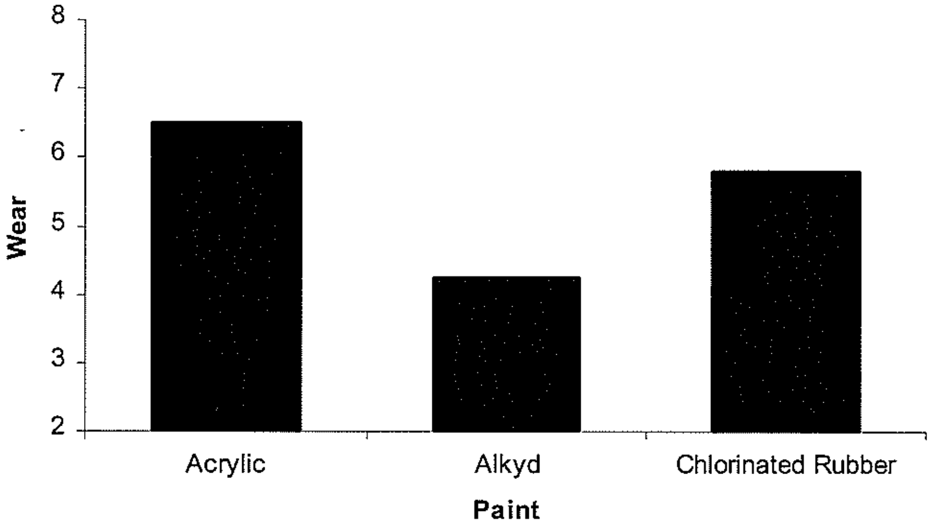
Table 9.1 Mean values of skid resistance and retroreflectivity.

Paint type	Wear		Retroreflectivity			
			BWP		LWP	
	Mean	Std dev.	Mean	Std dev.	Mean	Std dev.
Waterborne acrylic	6.5	1.6	177	42	165	41
Chlorinated rubber	5.9	1.0	158	29	144	29
Alkyd	4.1	1.2	92	20	82	24

9.1.1 Wear

The mean rates of wear for the three paint types are significantly different (*F* (2,409) = 101.06, p.<.001). Waterborne acrylic showed the least amount of wear, with a mean of 6.5 on the 10-point photographic scale (standard error (SE) = .116). Alkyd performed the poorest, with a mean of 4.2 (SE = .116) and chlorinated rubber performed with a mean of 5.8 (SE = .110). Post-hoc tests revealed that the differences in performance between chlorinated rubber and waterborne acrylic paints is significant (p.<.05), as is the difference between alkyd and chlorinated rubber. The data are illustrated in Figure 9.1.

Figure 9.1 Mean wear by paint type.



9.1.2 Retroreflectivity

Retroreflectivity also showed significant variation across paint types for both BWP (*F* (2,214) = 138.98, p.<.001) and LWP retroreflectivity (*F* (2,218) = 142.16, p.<.001). Alkyd paints performed poorest, with a mean of 83 (± 7.5) for BWP retroreflectivity and 81 (± 7.1) for LWP retroreflectivity. Waterborne acrylic paints performed best, with means of 177 (± 7.61) and 165 (± 7.2) for BWP and LWP retroreflectivity respectively. These data are illustrated in Figures 9.2 and 9.3.

Figure 9.2 Mean retroreflectivity of paint types, BWP.

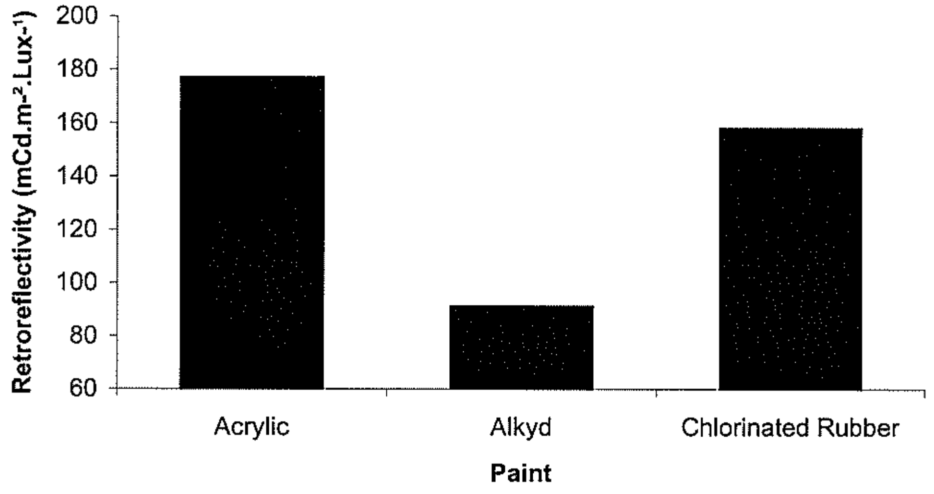
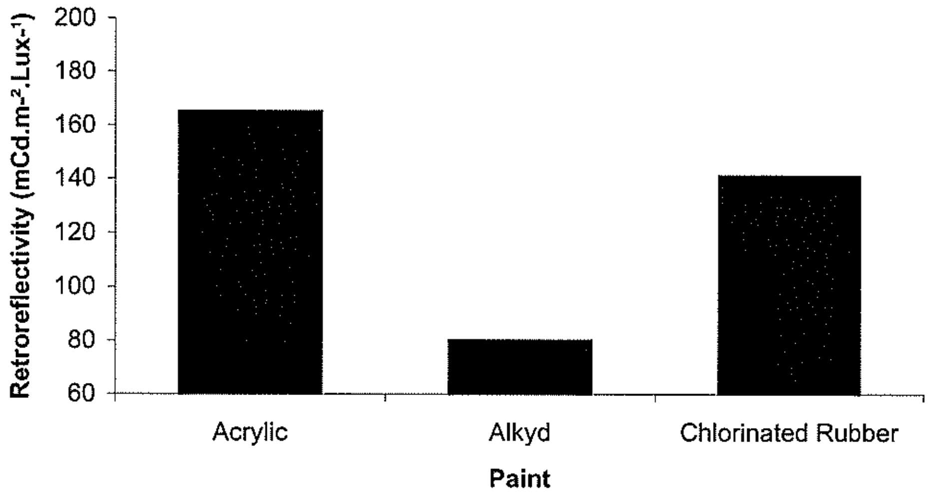


Figure 9.3 Mean retroreflectivity of paint types, LWP.

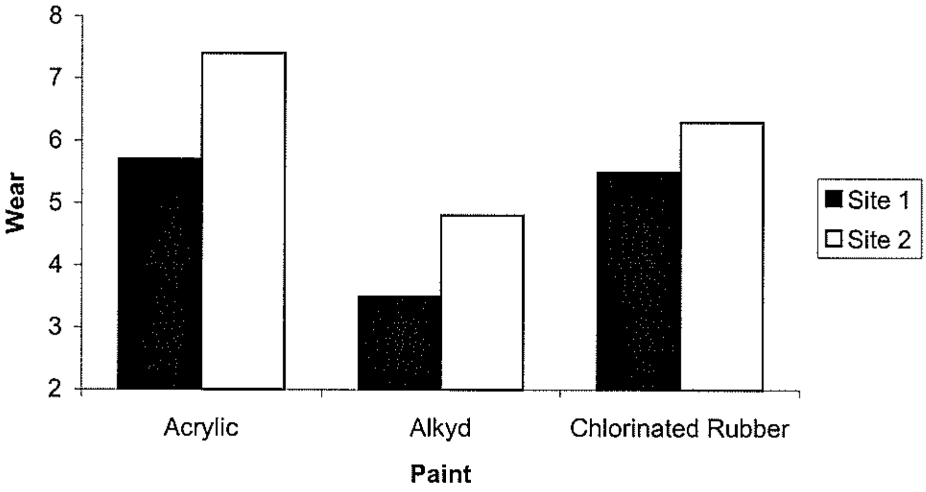


9.2 Site Differences

The sites on which the paint was laid appeared to have a significant effect on the rate of wear and loss of retroreflectivity. The two sites remaining in the study, Harcourt Werry Drive (Site 1) and SH2 at Moonshine (Site 2), showed significant effects.

The sites on which the paints were laid differed in the rates of wear (*F* (1,415) = 134.415, p.<.001). Importantly, there is an interaction effect with paint type (*F* (2,415) = 3.710, p.<.025. The differences in the rates of wear between sites varied according to paint type. These data are represented in Figure 9.4.

Figure 9.4 Variation of wear between trial sites.



The results for wear were reproduced for BWP retroreflectivity, where site effects were significant (*F* (1,220) = 7.659, p.<.006). An interaction with paint type was also observed (*F* (2,220) = 3.343, p.037). These data are represented in Figure 9.5 on page 52. Alkyd paints performed equally across the sites, whereas waterborne acrylic and chlorinated rubber paints performed with a marginal difference due to the site. The same pattern of results was observed for LWP retroreflectivity. There was a main effect for site (*F* (1,224) = 21.137, p.<.001) and an interaction effect for paint type (*F* (2,224) = 3.495, p.<.032). Again, alkyd paints seemed not to display the same differences in performance on the two sites that was noted for waterborne acrylic and chlorinated rubber paints (see Figures 9.5 and 9.6 on page 52).

Figure 9.5 Variation of retroreflectivity for the three paint types, BWP.

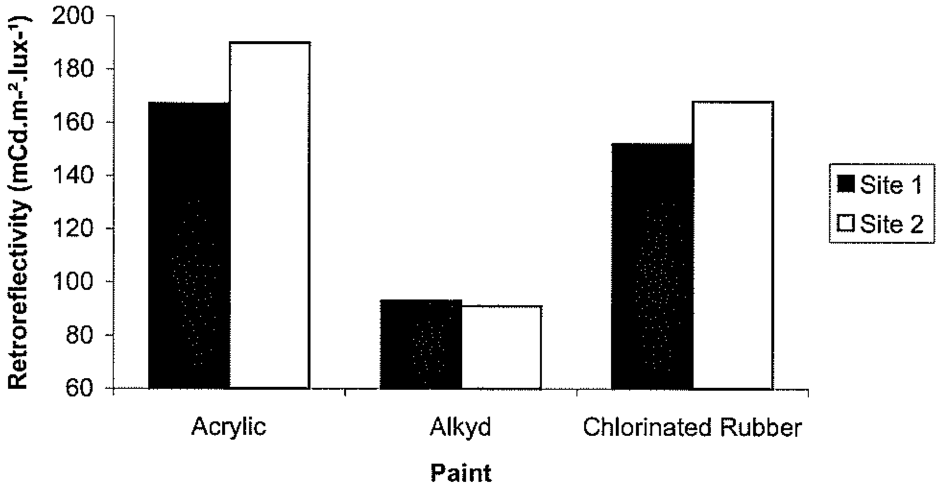
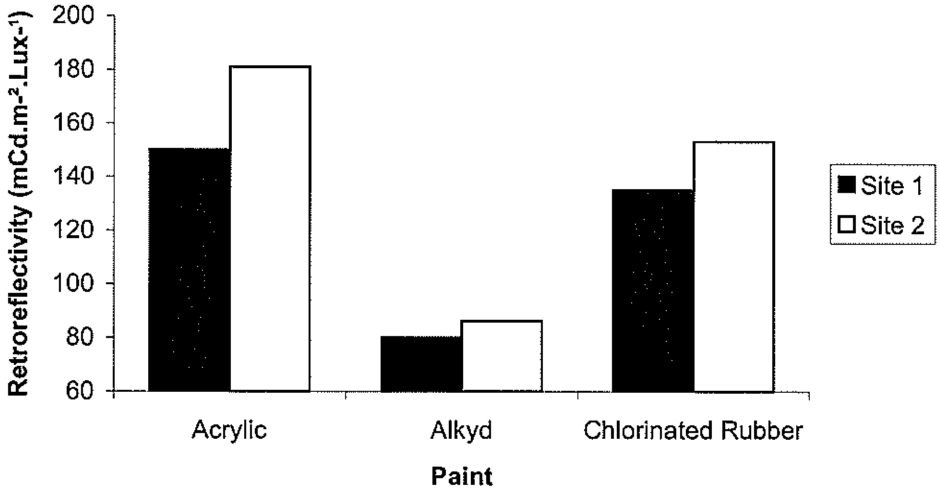


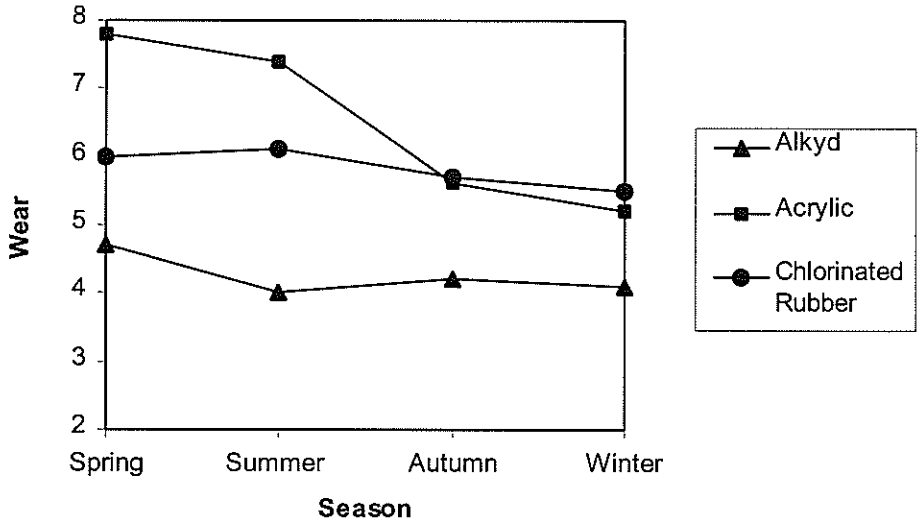
Figure 9.6 Variation of retroreflectivity for the three paint types, LWP.



9.3 Seasonal Effects

The season in which the paints were laid had a significant effect on the rate of observed wear (*F* (3,409) = 20.33, p.<.001). Paints laid in spring and summer performed better than those laid in winter and autumn. Post-hoc tests revealed that the effect was significant (p.05) but that no difference could be observed for those laid in spring compared with summer, and no significant difference for those laid in autumn compared with winter. This effect is illustrated in Figure 9.7.

Figure 9.7 Effect of season of application on wear.



As Figure 9.7 shows, these seasonal effects were not uniform across paint type (*F* (6,409) = 11.27, p.<.001). Table 9.2 provides the data for the influence of season on paint type, and shows the confidence interval of the mean effect by season.

Table 9.2 Seasonal effect on wear and confidence interval of mean

Paint type	Season	Mean wear	95% confidence interval	
			Lower boundary	Upper boundary
Waterborne acrylic	Spring	7.8	7.2	8.5
	Summer	7.4	7	7.7
	Autumn	5.6	5.2	6
	Winter	5.2	4.8	5.6
Alkyd	Spring	4.7	4.0	5.3
	Summer	4	3.7	4.2
	Autumn	4.2	3.8	4.6
	Winter	4.1	3.7	4.5
Chlorinated rubber	Spring	6.1	5.5	6.6
	Summer	6.1	5.8	6.4
	Autumn	5.7	5.3	6.2
	Winter	5.4	5.0	5.9

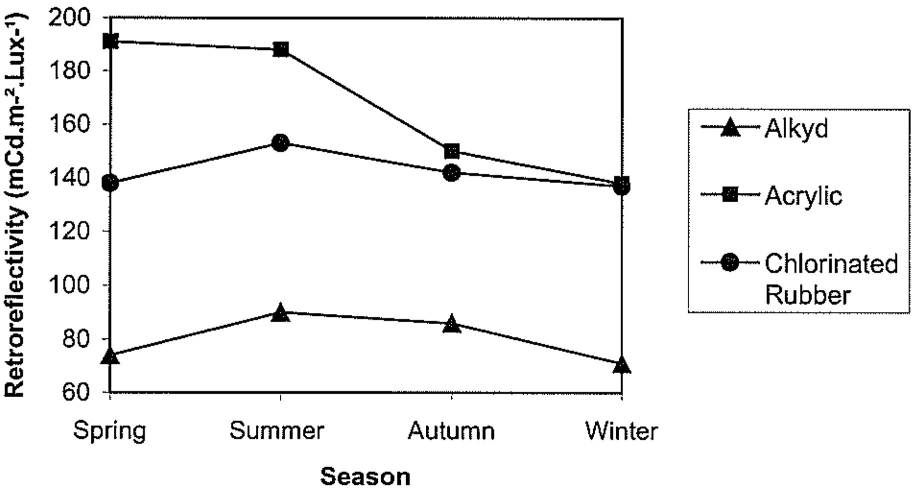
The paint most affected by season was waterborne acrylic: the mean observed wear dropped from 7.8 (± 0.7) when laid in spring to 5.2 (± 0.4) when laid in winter.

The season in which the paint was laid also had a significant effect on retroreflectivity. Table 9.3 shows the mean LWP retroreflectivity by paint type and season, and the confidence interval associated with that mean. The effect is most pronounced for waterborne acrylics. Figure 9.8 illustrates these data.

Table 9.3 Variation of LWP retroreflectivity by season.

Paint type	Season	Mean retroreflectivity (mCd.m^{-2}.Lux^{-1})	95% confidence interval of mean retroreflectivity (mCd.m^{-2}.Lux^{-1})	
			Lower bound	Upper bound
Waterborne acrylic	Spring	191	162	211
	Summer	187	177	197
	Autumn	148	134	163
	Winter	133	121	146
Alkyd	Spring	74	55	94
	Summer	90	80	100
	Autumn	86	72	100
	Winter	73	62	85
Chlorinated rubber	Spring	138	122	154
	Summer	153	143	163
	Autumn	144	130	158
	Winter	131	117	146

Figure 9.8 Effect of season of application on LWP retroreflectivity.



9.4 Effects of Time of Day of Application

Whether the paint was laid in the morning or the afternoon had no influence on the rate of wear (*F* (1,334) = 3.796, p.<.052). There was no interaction with paint type, as illustrated by Figures 9.9 and 9.10.

Figure 9.9 Effect of time of day of application on wear.

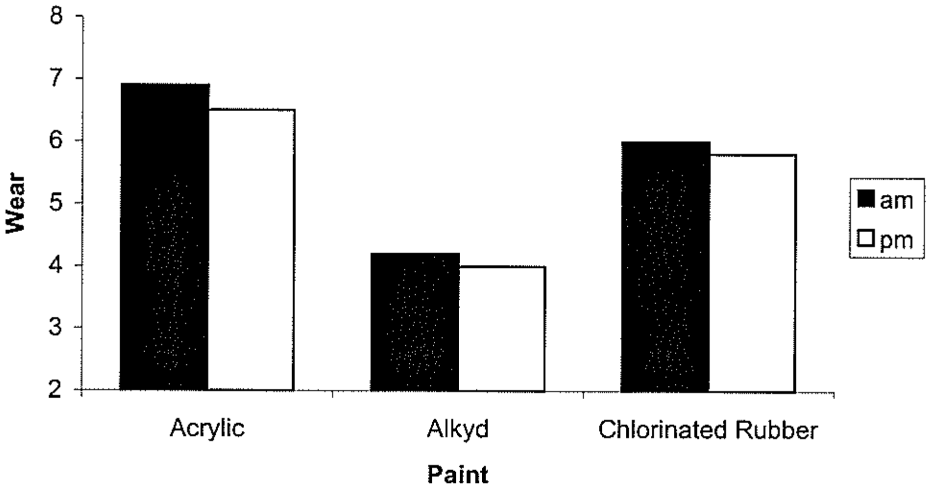
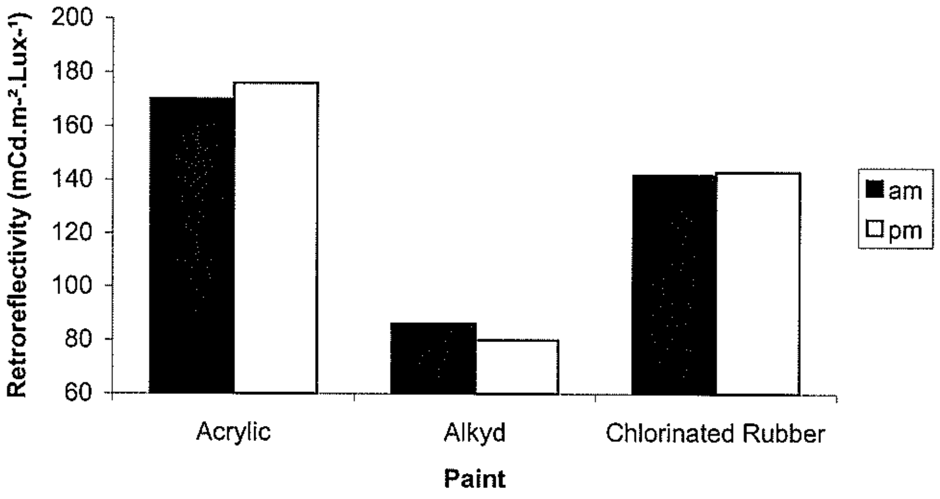


Figure 9.10 Effect of time of day of application on retroflectivity, LWP.



Similarly, BWP retroreflectivity was not influenced by whether the paint was laid in the morning or afternoon (*F* (1,179) = .900, p.<.344), nor was LWP retroreflectivity (*F* (1,183) = .002 p.<.961).

No interaction effects were observed for paint type and time of day of application for either BWP or LWP retroreflectivity.

9.5 Effects of Application on Different Days

Significant effects were observed for the different days on which the paints were laid (*F* (2,412) = 5.078, p.<.007). Day and day-after laying effects were compared (with three levels compared on three consecutive days).

The day of laying the paint influenced the rate of wear significantly (p.<.05) but the extent of the influence depended on the paint type (*F* (4,412) = 4.214, p.<.002). Waterborne acrylics showed much greater effect of the conditions on the day of laying than alkyd or chlorinated rubber paints, which did not differ according to the day of application. These data are represented in Figure 9.11.

Figure 9.11 Effect of day of application on wear.

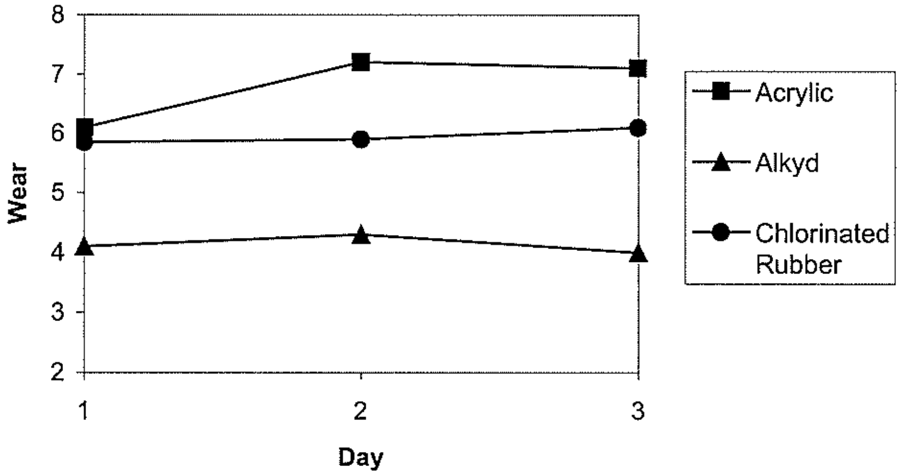
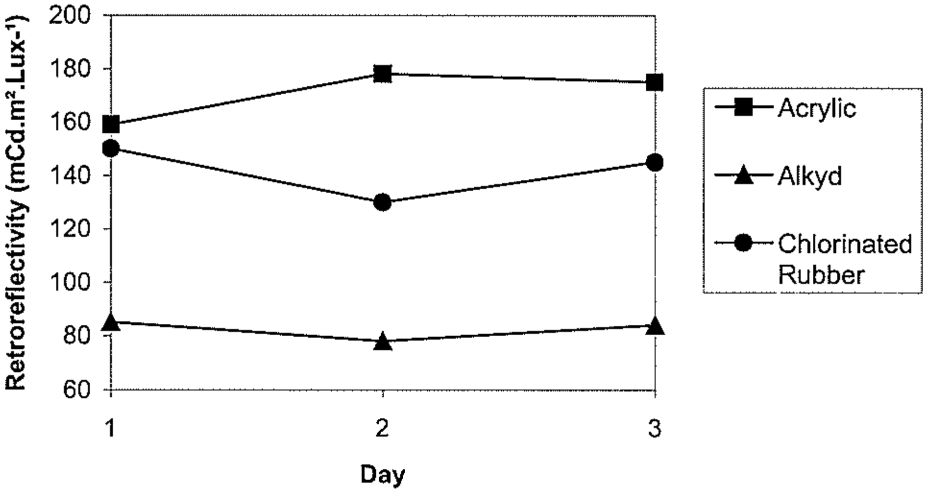


Figure 9.12 Effect of day of application on retroreflectivity, LWP.

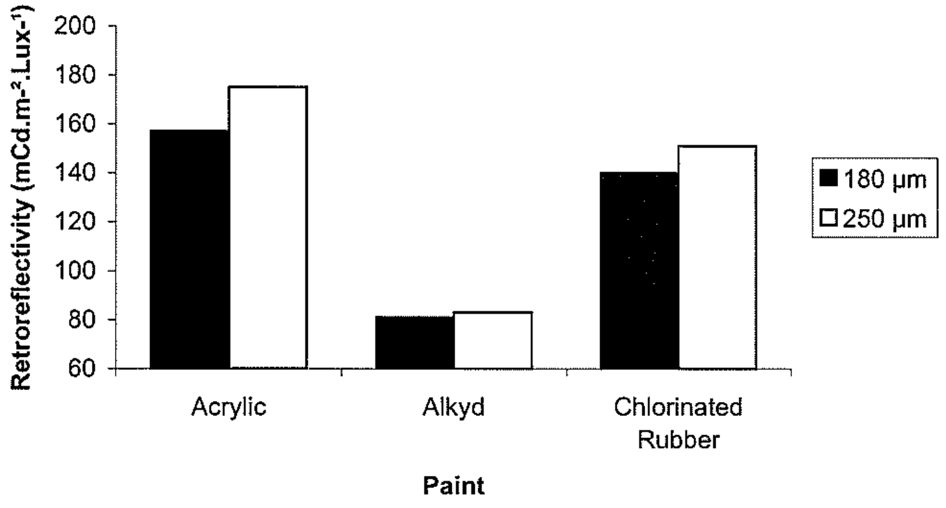


The observations for retroreflectivity were similar to those for wear in that there were some significant effects of day/day-after laying, but the extent varied with paint type (*F* (4,221) = 2.846, p.<.025). The effect was confined to the relative performance of chlorinated rubber and waterborne acrylic paints; alkyd paints are relatively insensitive to day-to-day fluctuations in conditions at the time of laying, as Figure 9.12 shows.

9.6 Target Thickness

Achieving the target thickness of the paint at either 180 µm or 250 µm did not appear to be a critical factor in paint performance with respect to wear, but it was for retroreflectivity. For wear, paint film thickness had no effect (*F* (1,415) = .009, p.<.925). Further, while no main effects were observed for BWP retroreflectivity (*F* (1,220) = 2.667, p.<.104), LWP retroreflectivity did show a main effect (*F* (1,224) = 6.82, p.<.01), the extent of which was related to paint type. Alkyd paints seemed to perform equally well whether the target thickness was 180 µm or 250 µm, whereas waterborne acrylic and chlorinated rubber paints showed some improvement in LWP retroreflectivity if the target thickness was greater. These data are illustrated in Figure 9.13.

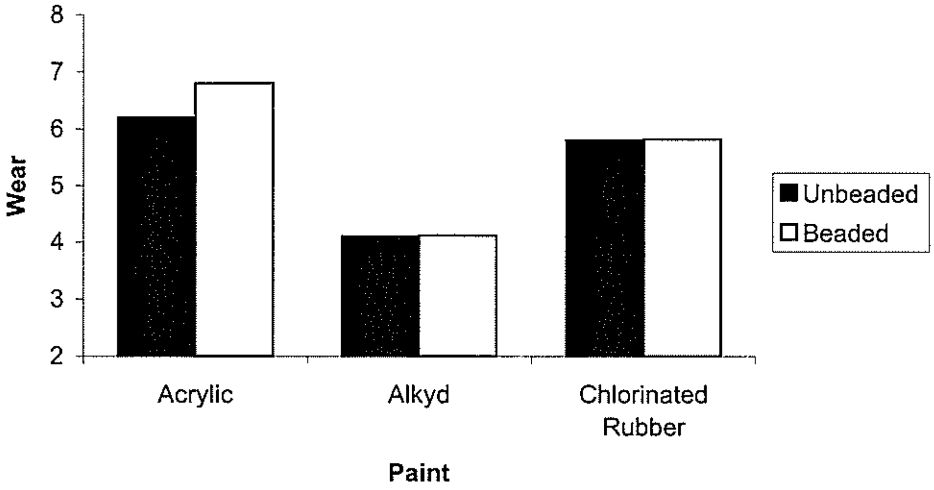
Figure 9.13 LWP retroreflectivity by target thickness and paint type.



9.7 Glass Beads for Reflectorisation

Where glass beads are added to increase reflectivity, their effect on improving resistance to wear was also considered. The influence of beads on the rate of wear was found to depend on the type of paint (*F* (2,415) = 3.269, p.<.039). Wear of alkyd and chlorinated rubber paints was not influenced by the presence of beads, whereas

Figure 9.14 Effect of reflectorisation on paint wear by paint type.



waterborne acrylic paints showed significantly less wear (mean 6.84, ± .30) with the presence of beads (p.05) than without beads (mean 6.1, ± 0.32), as is shown in Figure 9.14. International literature states that often reflectorisation also improves wear. This, however, has generally not been evident in New Zealand before, possibly because of the manner in which paint is lost from the road surface, and the quite rapid wear of paint off chipseal surfaces. The improved performance of the acrylic paint may now allow this improvement to become evident.

10. Discussion of results

10.1 Factors Influencing Performance

Table 10.1 shows the factors that influenced the performance of paints in the field trials.

Table 10.1 Factors influencing paint performance in field trials

	Wear				Wheel path retroreflectivity			
Factor	**All paints**	**Paint interaction**			**All paints**	**Paint interaction**		
		WB	**CR**	**Alkyd**		**WB**	**CR**	**Alkyd**
1. Site	√	√	√	√		√	√	**X**
2. Season		√	√	**X**	√	√	√	√
3. Time of application	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
4. Day of application		√	**X**	**X**		√	√	**X**
5. Thickness	**X**	**X**	**X**	**X**		√	√	**X**
6. Glass beads added		√	**X**	**X**		N/A	N/A	N/A

Notes:
WB = waterborne acrylic
CR = chlorinated rubber
√ = significant effect
X = no significant effect
Factor = variable tested
Paint interaction = significance of variable for each paint type.

To summarise the results:

- The site effect is so significant that it affects all paints, but is stronger for some paint types.
- The time of day at which the paint was applied had no influence for any of the paint types.
- Of the other effects, the season effect was strong for waterborne acrylic and chlorinated rubber but weak for alkyd paints.
- The remaining effects of day of application, paint thickness, and the addition of glass beads on wear, were generally not strong, but were sometimes significant for one or two of the paint types.

10.2 Discussion of Results

A trend shown by Table 10.1 is for alkyd paints to be generally unaffected by the field trial variables (other than site) and for waterborne acrylics to be influenced by most of the factors. This is of interest in considering the evolution of road-marking paints. Until about five years ago, waterborne paints were seldom used on New Zealand roads and the main paint submitted for trials was alkyd material.

The table also demonstrates that the previous practice of starting testing throughout the year was reasonable. The effect of different sites serves to confirm, however, that the variable performance of alkyd paints in these trials may have been due to the lack of a fixed trial site. Trials were conducted at one location for one to two years, then moved to another site when the first location was no longer available – because of road works, for example.

While the site effect was strong for wear, affecting the assessment by two points on the photographic scale, it was only moderate in affecting retroreflectivity. The main paint types being submitted for testing are increasingly acrylic and chlorinated rubber, which are selected primarily for their retroreflectivity performance, as their resistance to wear is already high. As a consequence, in the future the influence of the site effect on paint selection is likely to be less than when selection was based primarily on the wear resistance of alkyd paints.

Although the waterborne acrylic and chlorinated rubber paints were more influenced by the variables of the field trial than alkyd paint, the actual performance is also relevant. The waterborne acrylic was the most variable but was still the highest-performing paint in all situations, while the alkyd was the least variable paint but the lowest-performing in all situations.

The lack of any effect for application at different times of the day is useful in reducing the cost of field trials. At present, control paints are laid at the start, middle and end of the day, so that a test marking can be compared with a control paint close to its time of application. As a consequence, 30–50% of the trial effort and test site space are taken up with control paints. The lack of variability throughout the day means that the number of controls can be reduced to one set of control paints per day.

The day/day-after effect, especially for retroreflectivity, shows that there is still value in including controls in the trial each day that test markings are laid.

The influence of thickness on retention of retroreflectivity for waterborne acrylic and chlorinated rubber paints shows that it is still important to control thickness in the trial. However, as the increase in thickness was large (an increase of 40%, from 180 μm to 250 μm) but the effect on increased retention of retroreflectivity was not strong, relaxation of the tight controls on thickness is reasonable.

The season effect is significant, especially for waterborne acrylic material, which performs significantly better when applied in spring and summer compared with autumn and winter. Actual conditions on the day of application for spring and autumn were similar, so the change in performance with season may be related to the extent of warm weather following application, as well as the cooler conditions on the day of application.

The season effect could be managed in several ways:

- Trial starts could be confined to spring or summer, especially for waterborne materials.
- Trials could be done at any time, with allowance made for the season effect.
- Trials could start in autumn, so as to identify the typical paint wear that might be experienced, as most re-marking is done in the stable weather conditions of late summer/autumn, to ensure satisfactory lines over winter.

The site effect also needs to be managed. It is unlikely that there will be a dedicated test site in New Zealand such as that in Britain or France, where a special lane is provided into which traffic can be detoured while test work takes place. One way to manage the site effect would be to run a series of pre-tests on possible sites, using control paints such as those used in this project. Sites showing a poor performance could then be excluded from use in a field trial. Results from the selected site could also be adjusted to an agreed norm using the control paints as a reference.

10.3 Relevance of Paint Field Trials

This project confirmed that there was variability in the results of paint performance in field trials, and identified the main influences on variability as: site, season and day-to-day conditions. An issue that needs to be addressed is the relevance of paint field trials to actual on-road performance of normal markings.

Paint field trials of the type specified in TNZ M/7 (which mirrors similar trials in Australia, Britain, France and the United States) have always been considered to be not fully representative of normal on-road performance. In field trials, application conditions are closer to the ideal, usually a much longer period of non-trafficking is provided, the site has such features as a straight road section and clean stable surface, and the trafficking experienced by transverse lines compared with longitudinal lines can have different effects, especially early in the marking life. Generally, the intent with field trials has been to keep conditions and site features constant, so far as practicable, so that variations in paint formulation can be matched against variations in effect on paint performance.

The variability in performance demonstrated by this project makes deriving this formulation/performance relationship more difficult. However, the use of control paints to moderate performance of the test paints assists this process. This project has already recommended modifications to current practice to make the use of control paints more effective. The paints used in this trial are very suitable for use as control paints, as their repeated testing has provided valuable information on how their performance can be expected to vary with different times and conditions of application.

Care is needed, however, in the ways in which information obtained from field trials is used. Performance in a single field trial is likely to be only an indicative predictor of the performance of a paint in normal on-road usage. The very conditions for which the trial was most variable – site, season and day-to-day conditions – are those most likely to vary in normal paint usage. Further information is needed for more certainty of performance. This can be provided in several ways. The manufacturer could undertake a series of field trials to establish the conditions which lead to obtained or marginal performance. (The current project is an example of such a multiple trial.) Alternatively, a paint manufacturer could work with contractors to obtain data on in-field performance. Collecting this data from several areas in the country would allow the band of likely performance to be more precisely known. (Such a system has already been discussed by an industry group.) One way of collecting this data would be for the contractor to provide the manufacturer with test data from performance-based contracts.

The variability in field trials demonstrated by this project shows that approval processes for paint types may be somewhat arbitrary for paints that perform close to the minimum standard. High-performing paints are likely to show a variation in performance but above the minimum standard. Similarly, low-performing paints are expected to vary but below the minimum. Marginal paints, however, are likely to vary around the minimum, so that they could fail in one trial and pass in another. Consideration should therefore be given to allowing manufacturers to provide reputable information of in-service performance to support field trial data for type approval purposes.

11. Conclusions and Recommendations

11.1 Conclusions

1. The field trial that is currently used to assess paint performance for approval, as specified in TNZ M/7, shows significant variability. The test site and season of application are major sources of variability. Conditions on the day of application and paint film thickness also had some effect for some paint types. Time of day of the application had no significant effect.
2. Although variable, the trial is systematic. Three paints which were expected to have a performance range from marginal to very good were trialled. The field trial clearly distinguished the relative performance of the paints tested.
3. The trial procedure of TNZ M/7 needs to be modified to better manage the variability (see also Recommendations):
    - sites may need to be pre-tested as suitable for trials,
    - fewer control paints need to be laid throughout the day,
    - the season effect needs to be managed, either by avoiding late autumn and winter application or by moderating results with respect to performance of control paints.
4. Paint field trials represent an effective way for manufacturers to gain knowledge of the performance of paint formulations and to guide formulation development. Repeat trials in which the conditions are varied provide a systematic way to identify the paint's sensitivity to conditions.
5. The factors which most affect trial variability will also reduce the accuracy of predicting normal on-road performance of a paint throughout New Zealand from field trial results. Data on the performance of a paint in normal use could also supplement data from field trials.
6. The variability of the trial means that a material that is acceptable, but marginal, could fail in one trial and pass a subsequent trial.

11.2 Recommendations

1. Paint field trials should be continued as one of the means of establishing paint performance.
2. The field trial for testing paints as specified in TNZ M/7 should be modified so as to include:
    - Pre-testing the trial site with "control paints", so as to identify its suitability as a stable test site.
    - The use of "control paints" to moderate seasonal and day-to-day variability, but with only one set of control paints per day.

- Widening paint film tolerances to ± 15% of the target application thickness.
- The use of procedures either to limit the season in which some paints should be trialled or to standardise results in relation to a common time of application.

3. Care is needed when excluding a marginal paint from type approval on the basis of a single field-trial test result. The performance of relevant control paints should also form part of the evaluation. In addition, consideration should be given to allowing other evidence of performance, such as data from normal marking use, to be included in the evaluation.

4. A system which helps road controlling authorities and road-marking contractors get the best available information on paint performance – by, for example, supplementing field trial data with data from normal marking use – should be encouraged.

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