Development of a Diagnostic Method for Road Markings Using Sequential Images Taken from a Traveling Vehicle

Takumi ASADA [a], Masayoshi TANISHITA [b], Shuichi KAMEYAMA [c]

[a, b] *Department of Civil and Environmental Engineering of Chuo University Department, Tokyo,112-8551, Japan*
[a] *E-mail: t-asada@civil.chuo-u.ac.jp*
[b] *E-mail: tanishi@civil.chuo-u.ac.jp*
[c] *Department of Civil and Environmental Engineering of Hokkaido Institute of Technology, Hokkaido,006-8585, Japan; E-mail:kameyama@hit.ac.jp*

Abstract: In snowy areas, snow-removal operations damage road markings. Currently, the decision on the repaint markings is made on the basis of the damage to the markings at points measured every 2-5 km. However, there is a large variation in the damage to markings, and it is therefore necessary to evaluate the damage not at points but continuously on a line. In this study, we developed a diagnostic method for road markings using images of the road surface taken at 20 m intervals from a vehicle. In addition, we proposed the road marking condition index (*RMCI*) on the basis of the appearance and nighttime visibility of markings. As a result, it was found that the number of sections to be repainted can be reduced by this method. Because *RMCI* can adjust the ratio of nighttime visibility and appearance, road administrators can set up a maintenance level in response to situations.

Keywords: Road markings, Image Analysis, Stripping Ratio, Nighttime Visibility, Appearance, RMCI

1. INTRODUCTION

Road markings provide motorists information such as directions and rules related to road traffic. In japan, the Road Act states that “road markings shall be provided at the necessary locations to ensure the integrity of the road structure and the safety of traffic.” Damage to road markings, such as soiling, wear, and stripping, normally occurs due to the passage of vehicles. In snowy regions, road markings are stripped by surface leveling and snow-removal operations, significantly reducing their visibility. Therefore, it is necessary to periodically inspect and repaint road markings. In Hokkaido, road markings are repainted every year after the snow melts, and the annual cost of repainting national roads, prefectural roads, and municipal roads amounts to approximately 3 billion yen. Because of the severe fiscal situation in Japan over recent years, public work expenditures are being continuously cut along with road maintenance and management costs. Against this background, it is necessary to evaluate damage to road markings in order to repaint road markings more precisely. In particular, considering the simplification of the repaint diagnostic, an objective or user-friendly evaluation method will help drive down the cost of the road marking service, as well as the overall road maintenance in local areas.

The Road Sign Handbook published by Japan Contractors Association of Traffic Signs and Lane Markings (1998), specifies a method whereby damage to road markings is evaluated in accordance with the following three criteria (Figure 1). Nighttime visibility is evaluated by measuring the coefficient of retroreflected luminance (reflectivity or *RF*) of glass beads dispersed on road markings (Kalchbrenner, 1989; Imada *et al*, 1990). Appearance and stripping are evaluated visually or from photographs on basis of daytime visibility (Hirasawa *et al*, 2008). Appearance is evaluated on the basis of the first impression of road markings made by five or more observers at a distance of approximately 3 m from the markings. To evaluate stripping, the proportion of the stripped area, i.e., stripping ratio, is obtained using enlarged photographs taken on site directly above road markings. In the handbook, if the integrated index of road marking condition calculated on the basis of the abovementioned three criteria is less than 3, it is concluded that road markings need to be repainted.

Individual evaluation

Evaluation rank	Nighttime visibility evaluation (reflectivity :mcd/m^{2}lx)	Appearance evaluation (first impression)	Stripping evaluation (stripping ratio:%)
5	≧ 246	Good, unchanged from initial construction	< 3
4	186 ～ 246	Some discoloration, but function of the sign is sufficient	3 ～ 8
3	126 ～ 185	Soiling, yellowing, bleeding, etc., can be seen	8 ～ 23
2	65 ～ 125	Soiling, yellowing, etc., is remarkable	23 ～ 40
1	< 65	Original form lost, flowing and soiling, visibility is poor	≧ 40

Overall evaluation

Integrated index of road marking condition
＝0.3A+0.3D+0.4N

A: Appearance evaluation rank
D: Stripping evaluation rank
N: Nighttime visibility evaluation rank

It is desirable that the index is 3 or higher

Figure 1. Method for evaluating road markings (Japan Contractors Association of Traffic Signs and Lane Markings, 1998)

Normally, a road marking evaluation is conducted at points located every 2–5 km. However, in snowy regions, damage to road markings due to snow removal varies significantly. Hence, a continuous damage evaluation is necessary, rather than a coarse evaluation every 2–5 km.

Therefore, to perform effective repainting of road markings, it is necessary to evaluate the amount of damage not at points but continuously on a line and diagnose the need for repainting with rational and objective criteria.

However, there has been little discussion on diagnostic methods of road markings from the abovedescribed viewpoint. On the basis of this situation, Asada *et al* (2011) developed a method of continuously estimating the stripping ratio (*SR*) of road markings from image features kurtosis of a density histogram (*KT*), correlation coefficient of co-occurrence matrix (*CR*), multifractal dimension (*D*(8)) that are calculated from photographs of the road surface taken at 20 m intervals from a traveling vehicle. On the basis of this study, Kinoshita *et al* (2011) conducted a reflectivity survey, and clarified the relationship between reflectivity and *SR*. However, in these studies, the validity of the criteria for repainting and an evaluation by drivers have not been considered.

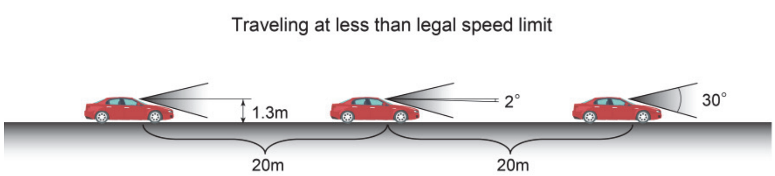
In this study, a questionnaire survey on the appearance of road markings using images of a road surface taken from a traveling vehicle was conducted, and a diagnostic method for road markings based on appearance and nighttime visibility was developed. Furthermore, the proposed method was applied to national roads within Sapporo City to evaluate its effectiveness.

2. EVALUATION METHOD OF STRIPPING RATIO AND REFLECTIVITY

2.1 Measurement of *SR*

In this study, road markings painted as a solid white line on the edge of the roadway were evaluated over almost the entire length of the examined road, except at crossroads. Route 36 (11.8 km) and Route 12 (13.3 km) on national roads within Sapporo were surveyed.

The road surface in front of a vehicle traveling on the leftside lane was photographed from the passenger seat at 20 m intervals by using a single lens reflex camera.



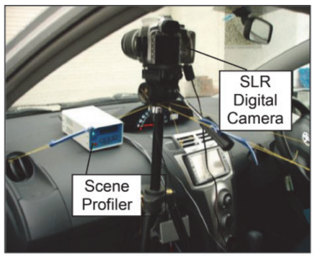


Figure 2. Measurement of road markings

As shown in Figure 2, the camera was mounted on the passenger seat at a height of 1.3 m from the road surface with a dip angle of 2°. The recorded image size was 2816 × 1880 pixels, with the shutter speed set to 1/320 second. Photographs were taken traveling at speeds less than the legal speed limit using a control device (scene profiler) that converted the speed pulse obtained from the vehicle control unit into the distance traveled; the control device transmitted a shutter signal to the camera at set distance intervals.

The survey was conducted on three occasions: twice in spring (May 2009, May 2010) prior to the repainting of road markings, and once in autumn (October 2009) after repainting. In all cases, photographs were taken when the road surface was dry, between 9:00 am and 4:00 pm, to account for reflections from the road surface and sunlight.

SR is calculated according to the flow shown in Figure 3 using images taken from a traveling vehicle (Asada, 2011). After converting the photograph to a grayscale image, the analysis area was cropped to the range of road markings at 20 m intervals—same as the shooting interval distance—using a template-matching method to detect the evaluation area from the analysis area. Next, we calculated the amount of the following three image feature types from the extracted evaluation area: *KT*, *CR*, and *D*(8). *SR* is calculated by substituting these values into Equation (1).

$$SR = 12.6\ln(KT) + 20.0\ln(CR) - 73.2D(8) + 215.5 \tag{1}$$

where,

KT : kurtosis of density histogram,

CR : correlation coefficient of co-occurrence matrix, and

D(8) : multifractal dimension (*q*-moments = 8).

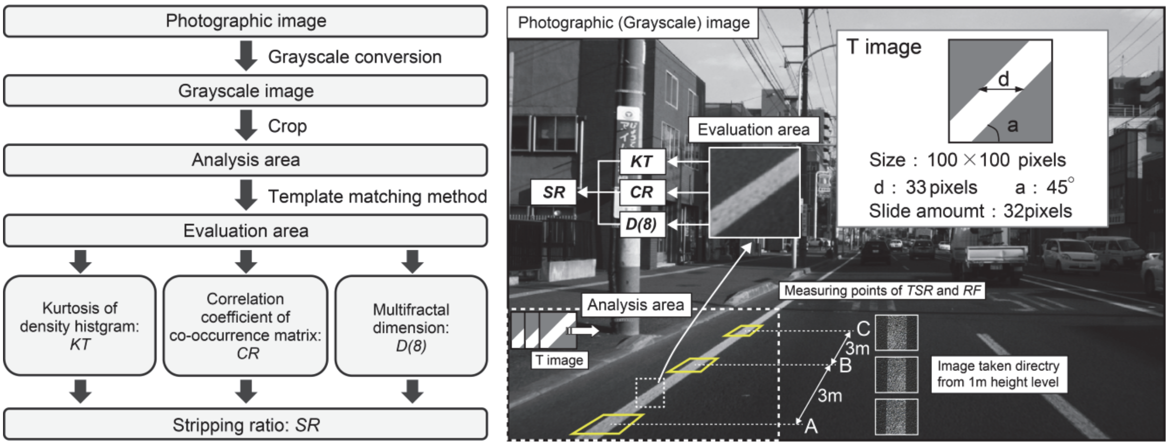


Figure 3. Calculation flow of *SR* and measuring points of *TSR* and *RF*

The features of a density histogram include statistical values for the gray level, such as the mean or standard deviation, which are available for general use as basic image features. *KT* is one of the features of a density histogram and decreases as the density histogram becomes flatter.

A feature of a co-occurrence matrix widely used in texture analysis can be used to evaluate the image on the basis of the array pattern of gray values. The *CR* value calculated from the co-occurrence matrix of an image expresses the degree of the proportional relation of the gray values of an adjacent pixel pair. *CR* increases as the striped or mottled pattern becomes more conspicuous.

The multifractal dimensions calculated using the box-counting method express the degree of heterogeneity of a geometric pattern. It was confirmed that moment dimension 8 was appropriate in the preceding study (ASADA, 2011).

Equation 1 was obtained using a multiple linear regression analysis. In the analysis, *SR* was the objective variable, and the image features were explanatory variables. *SR* was calculated by a road maintenance professional using image thresholding.

Table 1. Multiple linear regression analysis of Equation 1 (Asada, 2010)

Coefficient of determination (R^2) = 0.83	ln(*KT*)	ln(*CR*)	*D*(8)	Intercept
Partial regression coefficient	12.6	20	-73.2	215.5
Standardised partial regression coefficient	0.29	0.56	-0.11	—
t value	5.2	16.1	-3.2	4.6
Single correlation coefficient	0.89	0.89	-0.75	—

F_{in} and F_{out} is 2 in stepwise method

To verify the validity of *SR*, the relationship between *SR* and the stripping ratio with the current method (*TSR*) was examined. The *TSR* survey was conducted at 50 locations, at a total 100 points for both Route 12 and Route 36. The photographs (Figure 3) were taken directly from the 1 m height level, and *TSR* was calculated by applying image thresholding to the photographs. Figure 4 shows the relationship between *SR* and *TSR*. The R^2 values of *SR* and *TSR* are sufficiently large, and therefore *TSR* can be reproduced accurately using *SR*.

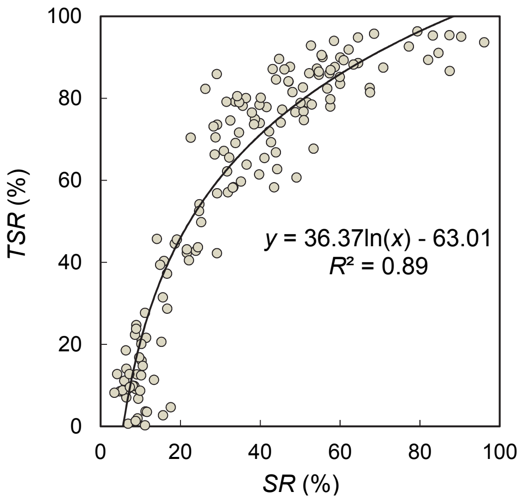


Figure 4. Relationship between *SR* and *TSR*

2.3 Relation between *SR* and Reflectivity

Reflectivity (*RF*) was measured at the same measurement points as *TSR* (Kinoshita, 2011). As shown in Figure 3, *RF* was measured at three points (A, B, and C) using MIROLUX 7. These average values were used in the following analysis.

Figure 5 shows the relationship between *RF* and *SR*. From this relationship, a nonlinear regression formula, Equation (2), can be obtained. The R^2 values of *SR* and *RF* are sufficiently large, and therefore *RF* can be estimated from *SR* using Equation (2).

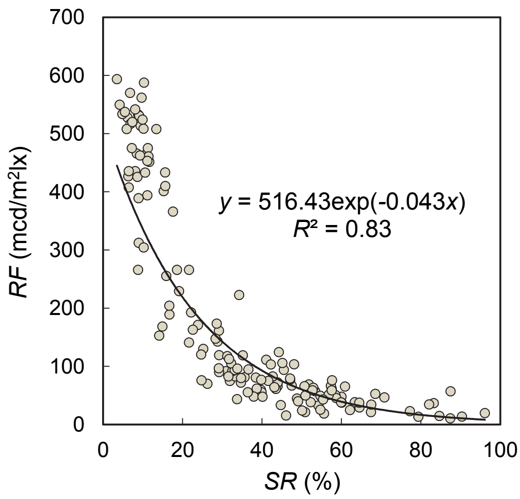


Figure 5. Relationship between *SR* and *RF*

$$RF(\text{mcd/m}^2\text{lx}) = 516.43e^{-0.043SR} \tag{2}$$

The R^2 values of *SR* and *RF* are sufficiently high (0.83), and the error is small under Abboud's criterion value (150mcd/m^{2}lx). However, the error value becomes higher than the criterion value. Therefore, with a proposal for a tougher (150mcd/m^{2}lx or more) *RF* criterion, it is necessary to consider the effect of stripping.

3. EVALUATION TEST OF APPEARANCE OF ROAD MARKINGS

3.1 Outline of Web-based Evaluation Test of Appearance

As shown in Figure 6, the evaluation test of appearance of road markings consists of evaluations of appearance, judgment on the need to repaint, and a survey of attributes. The test was conducted over the Internet.

Item of questionnaire

Items		Choices
Evaluation of appearance		Bad ← 1 ・ 2 ・ 3 ・ 4 ・ 5 → Good
Judgement of the need to repaint		Necessary ・Unnecessary
Survey of attribute	Residential area	Prefectures
	Sex	Male・Female
	Age	10s・20s・30s・40s・50s・60s～
	Occupation	Road marking industry worker・Civil engineer・Except civil engineer・Student・Others
	Driving experience	Nothing・~2year・2~5year・5~10year・10~20year・20year~

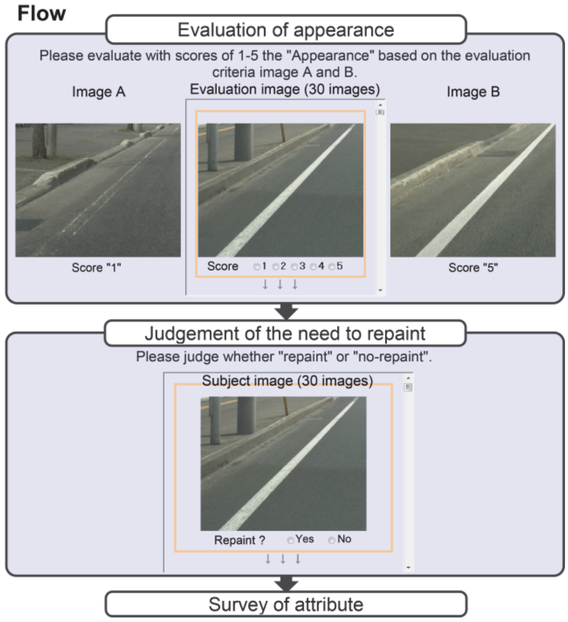


Figure 6. Outline of the web-based questionnaire survey

In the "evaluation of appearance," the examinee looks at the evaluation image presented and evaluates the appearance of road markings on the basis of five possible scores (1, 2, 3, 4, and 5). The criterion images A (*SR* = 7%) and B (*SR* = 91%) are selected from images without obstructions and shadows. A total of 30 sheets of evaluation images (*SR*: 8–86%) without obstructions and shadows were chosen from the photograph taken in the *SR* survey. After the "evaluation of appearance" for all images is conducted, a "judgment on the need to repaint" is performed on the same images. Finally, an "attribute survey" is conducted.

The web-based evaluation test was conducted in the period from November 27, 2009 to January 15, 2010.

3.2 Relationship between *SR* and Appearance

The evaluation tests of appearance were taken by a total of 733 people, which included 672 males and 61 females. Figure 7 shows the attributes of the examinees. Approximately 80% of them live in Hokkaido. Approximately 10% of them are road-marking industry workers (specialists), whereas others (general people) account for approximately 90%.

To determine the difference between specialists and general people, a student's t-test was performed on an average value (*AV*) of the appearance score for both groups. As a result, as shown in Figure 8, it was found that the *AV* of specialists (*AVs*) was smaller than the *AV* of general people (*AVg*), and the proportion of images that generated a significant difference was 70%. This means that specialists tend to evaluate the appearance of road markings more rigorously than general people. Therefore, in this study, the data for general people and specialists was not merged but analyzed for each group.

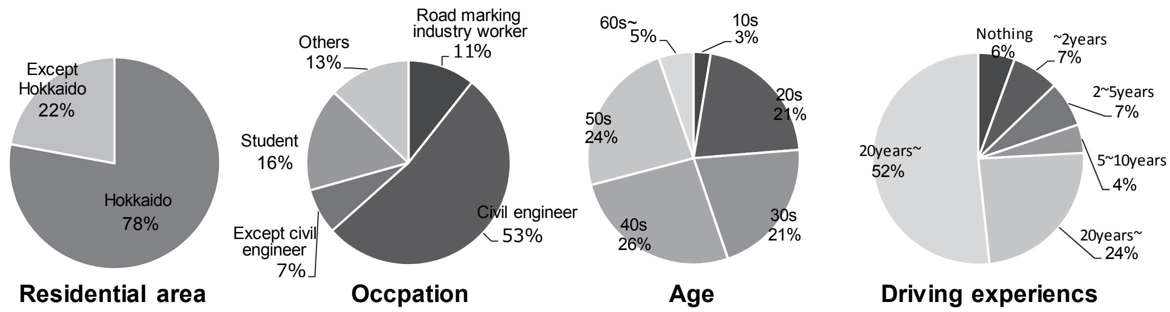


Figure 7. Attributes of the examinee

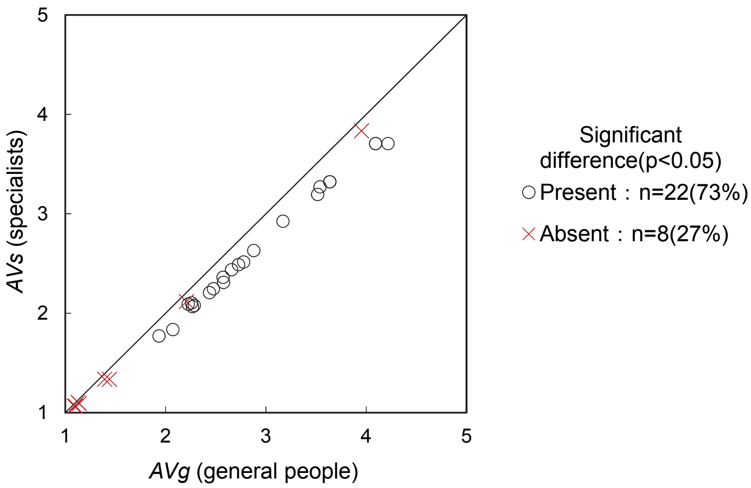


Figure 8. Relationship between *AVg* and *AVs*

Figure 9 shows the relationship between *SR* and *AV*. It was found that *AV* decreased with an increase in *SR*. The regression equations of *AVs* and *AVg* are expressed by Equations (3) and (4), respectively. The R^2 value is sufficiently large, and therefore it is possible to estimate *AVs* and *AVg* from *SR* by using these equations.

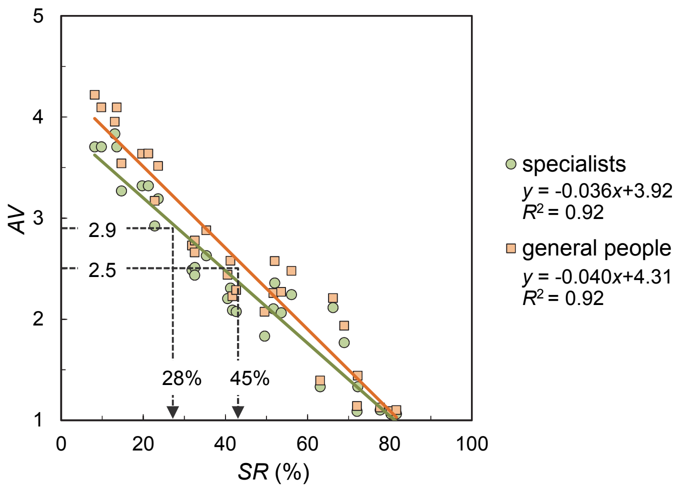


Figure 9. Relationship between *SR* and *AV*

$$AVs = -0.036SR + 3.92 \tag{3}$$

$$AVg = -0.040SR + 4.31 \tag{4}$$

3.3 Relationship between *DSR* and Judge of Repaint

In the evaluation test, we also obtained responses regarding the necessity of repainting. Therefore, for each evaluation image, the percentage of examinees who responded affirmatively to the need for repaint (*NP*) is calculated. Figure 10 shows the relationship between *AV* and *NP*. It was found that the R^2 value of specialists and general people is sufficiently high. Therefore, it is possible to estimate *AV* from *NP* using the equation in Figure 10. For *NP* = 50% (half of the examinees who saw a need for repainting), *AVs* and *AVg* were 2.9 and 2.5, respectively.

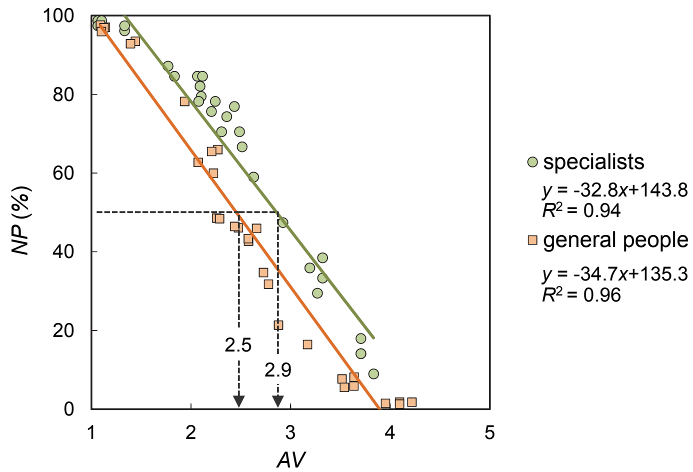


Figure 10. Relationship between *AV* and *NP*

Next, *AVg* and *AVs* were substituted in Equations (3) and (4), respectively, and *SR* corresponding to *NP* = 50% can be calculated. As a result, the *SR* values of specialists and general people were 28% and 45%, respectively. This means that the specialists who were harsh (Figure 8) in their evaluation of appearance were also tough judges for the need to repaint.

As shown in Figures 9 and 10, the *SR* values (repaint criterion of *SR*) corresponding to *NP* = 50% were 45% and 28% for specialists and general people, respectively. Coincidentally, Abboud (2002) reported that there is need to repaint road markings when *RF* is less than 150mcd/m^2lx. If the criterion value (150mcd/m^2lx) of *RF* is substituted into Equation (2), *SR* becomes 28%. This value is approximately equal to the repaint criterion of the *SR* of specialists. Therefore, in diagnosing the need for repainting road markings, general people decide the need on the basis of appearance, while specialists tend to decide on the basis of the nighttime visibility from the analogical inference of appearance with their experience.

4. DIAGNOSTIC FOR ROAD MARKINGS USING SEQUENTIAL IMAGES

On the basis of the previous analysis, we propose a new diagnostic method for road markings. Furthermore, we conducted a diagnosis of the need to repaint road markings on survey routes using the proposed method and discussed its effectiveness on the basis of the results.

4.1 Criterion of Repaint Based on Appearance and Nighttime Visibility

There are existing diagnostic methods for road markings, such as the integrated index (Figure 1) of Japan Contractors Association of Traffic Signs and Lane Markings. It includes an integrated index based on three evaluation items: stripping ratios, nighttime visibility, and appearance. Appearance and nighttime visibility correspond to the daytime visibility and reflectivity, respectively. However, it is not clear what corresponds to stripping ratio. Furthermore, as shown in Figures 5 and 9, RF and AV are functions of stripping ratio. Therefore, it is not appropriate to use stripping ratio in the integrated index in the same way as RF and AV.

In this study, we proposed road marking condition index (*RMCI*) for the evaluation of road marking condition on the basis of appearance and nighttime visibility. In this method, the index (real numbers in the range 1–5) of appearance (*AI*) and nighttime visibility (*NI*) is calculated from *SR*. *RMCI* is obtained by substituting *AI* and *NI* into Equation (5).

$$RMCI = (1-\alpha)AI + \alpha\, NI \tag{5}$$

where,

AI : Index of appearance,
NI : Index of nighttime visibility, and
α : weight coefficient.

RMCI is a real number ranging from 1 to 5. It is deemed that the condition of road markings is better as the value increases. Road markings are repainted when *RMCI* is below 3, which is similar to the case in the integrated evaluation method (Figure 1). The weight coefficient α is a real number in the range 0–1 and represents the importance of nighttime visibility.

AI is calculated from *AV* (average value of appearance score) on the basis of the web-based evaluation survey of appearance. As described above (Section 3.3), specialists tend to decide on the need to repaint on the basis of nighttime visibility from the analogical inference of appearance. Therefore, *AI* is calculated using the equation for *AVg* (Equation (4)). As shown in Figure 10, specialists and general people have approximately the same slope for the regression equation. Thus, *AI* is calculated by Equation (6), which is higher than Equation (4) by 0.5, in order to correspond to $AVg = 3$ for $NP = 50\%$.

$$AI = -0.040SR + 4.81 \tag{6}$$

Because an evaluation test of nighttime visibility was not conducted in this study, the relationship between *NI* and *SR* cannot be obtained directly in the same way as *AI*. Therefore, as reference, we used the reflectivity ranks (Figure 1) of Japan Contractors Association of Traffic Signs and Lane Markings. On the basis of the regression equation for *RF* and *SR* (Figure 5), *NI* = 1, 2, 3, 4, and 5 corresponding to *RF* (mcd/m^2lx) = 5, 65, 125, 185, and 245, respectively. As a result, the relationship between *NI* and *SR* were expressed as shown in Equation (7).

$$NI = \frac{(516.43e^{-0.043SR} - 5)}{60} + 1 \tag{7}$$

4.2 Diagnostic for Road Markings in the Survey Route

The profile of *RMCI* (Figure 11) was obtained by applying the proposed method to the images of a road surface taken at 20 m intervals from a traveling vehicle. This means that a section of $RMCI < 3$ requires repainting.

Figure 12 shows the percentage of the repaint section when varying the weight coefficient α. For $\alpha = 0$, *RMCI* is determined by *AI*, and therefore the percentage of the repaint section is equal to the result of using the criterion of *AVg* individually. Because the criterion of *RF* is stricter than that of *AVg*, the repaint section increased with α. For $\alpha = 1$, the proportion of the repaint section is equal to the result of using the criterion of *RF*. As shown in Figure 11, the repaint section varies according to α. On the other hand, almost all sections on the survey routes in Sapporo City were repainted every year. Therefore, it is possible that the length of the repaint section is reduced significantly by using the proposed method regardless of the value of α.

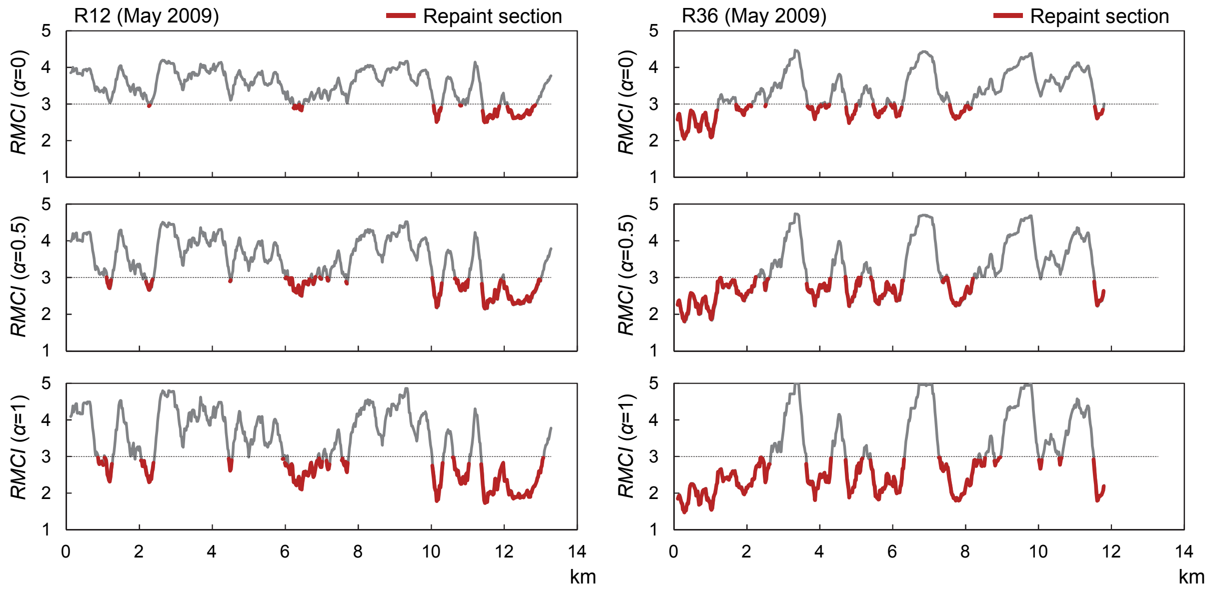


Figure 11. Profile of *RMCI* on survey routes before repaint (Case of α=0, 0.5, 1)

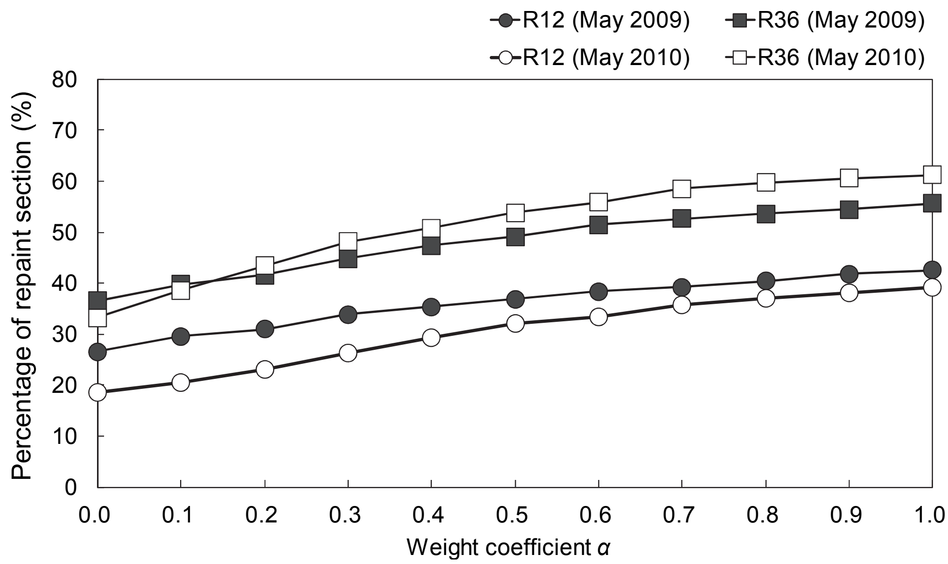


Figure 12. Relationship weight coefficient α and percentage of repaint section

4.3 Feature of the Development Method

Road administrators can adjust the weight coefficient α according to the situation. For example, α is set to be lower on tourist roads and routes that have little traffic volume at night. On the contrary, α is set to be higher, with an emphasis on safety, on a large percentage of traffic routes such as city roads and highways used at nighttime. In addition, in recent years, in circumstances such as global environmental issues and the reduction of public work budgets in Japan, there has been an increase in cases where the illumination intensity of road lighting is reduced. In such cases, α is set higher than usual, while the illumination settings are lowered. Therefore, strategies such as maintaining a high level of nighttime visibility of road markings can be considered.

Table 2 shows a comparison of the proposed method in this study and the visual evaluation method that is currently used in the survey routes.

In the survey routes, the necessity of repainting is annually determined by a visual evaluation method. As a result, repainting was done on almost all sections. On the other hand, the proposed method can diagnose road markings at short intervals of 20 m using the *RMCI* profile, and can reduce the repaint sections by about half.

Table 2. Comparison of the proposed method and the visual evaluation method

	Visual evaluation method	Proposed method
Accuracy	・Visual evaluation at 2–5 km intervals	・*RMCI* profile of 20 m intervals ・Setup of the construction section length by use of the average value of corresponding intervals
Work efficiency	・Movement by patrol car ・Visual inspection by evaluation of 2–3 people in the car	・Install of measurement equipment to car (or passenger car) and normal speed traveling with the car ・Calculation of the *RMCI* and specified the repaint section by use of an analysis software
Cost	・Cost of the vehicle ・Labor cost of survey and analysis (2–3 people)	・Cost of the vehicle ・Labor cost of survey and analysis (1 person) ・Measurement equipments ・Analysis software

In the case of the visual evaluation method, the patrol car is stopped temporarily when it reaches the observation point, and road markings are diagnosed by two or three observers. Because images of the road surface are taken from a traveling vehicle at the legal speed limit, the time and effort required in the proposed method are less than those in the visual evaluation method. Moreover, the calculation of the indicators (*RMCI*) and processing of various images are performed automatically by the analysis software developed by the authors.

Initial cost of the proposed method is slightly higher than the visual method. However, the survey cost is less than 5% of the cost of entire services of the repaint of road markings. And furthermore, the repaint sections can be significantly reduced through the use of the proposed method. Therefore, this method can contribute to reduction of the maintenance costs of the road markings.

Outside of snowy areas, investigations and the repainting of road markings are performed every 3–5 years because the progression of damage is slow. However, in local and semi-mountainous areas, the road markings have a higher damage frequency, and it is thus necessary to investigate the road markings at shorter intervals (e.g., every year) using a method such as ours to ensure road traffic safety.

5. CONCLUSION

In this study, we propose an evaluation test of the appearance of road markings performed using images of the road surface taken from a traveling vehicle and a diagnostic method for the need to repaint road markings. As a result of the evaluation test, it was found that the average of appearance score (*AV*) can be estimated from *SR*. Furthermore, we proposed an index (*RMCI*) for the diagnosis of the condition of road markings based on appearance (daytime visibility) and reflectivity (nighttime visibility). It is possible to reduce the sections marked for repainting using *RMCI,* which is calculated from images taken at 20 m intervals from a traveling vehicle.

In the future, we will clarify the relationship between the visual evaluation of human and nighttime visibility (*RF*). And then consider the diagnostic and analysis methods that can be applied to other types of damages in addition to stripping. The method can be applied to other areas besides snowy areas and can contribute to the efficiency of road maintenance in various areas suffering from severe economic conditions.

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