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Evaluating Suitable Application of De-Icing Materials for Winter Maintenance Practices

Jinguk Kim[1], Choongheon Yang[2], Amelia C Regan[3], Geunhyong Park[4]

[1]*(Highway And Transportation Research Institute/ Korea Institute Of Civil Engineering And Building Technology, Korea)*
[2]*(Highway And Transportation Research Institute/ Korea Institute Of Civil Engineering And Building Technology, Korea)*
[3]*(Department Of Computer Science And Institute Of Transportation Studies, University Of California At Irvine, USA)*
[4]*(Highway And Transportation Research Institute/ Korea Institute Of Civil Engineering And Building Technology, Korea)*
Corresponding Author: Jinguk Kim

ABSTRACT: *This study evaluated the differences in estimated and actual use of de-icing materials across regions in South Korea. We use this information to identify areas where there appears to be a misfit between estimated and actual use and also to improve future use estimates. Using the right amount of de-icing materials has implications for winter maintenance costs as well. For the period 2011 through 2016, we examined estimated and actual use by region and the differences between these two values using two statistical tests that identified statistically significant differences in use in some regions. The results show that it is important to evaluate the appropriateness ofuse of de-icing materials in each region every year.This study can be applied in a variety of other locations to identify mismatches in material use as specific decision-making based on suitabledata analysis is importantfor costreduction and environmental impact.*

KEYWORDS *-De-icing Materials, Wilcoxon Signed Rank Test, Kolmogorov-Smirnov Test (K-S test), standard application amount*

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I. INTRODUCTION

The frequency of heavy snowfall on the Korean Peninsula has increased over the last several decades, with the most damage from snow storms occurring in 2010. At that time,almostall transportation was suspended for three days, with onlythe subway system in operation, as can be expected. Thus, urban functions in the Metropolitan area (see Figure 1 below for a map of the regions) were temporarily paralyzed (Kim and Yang, 2017). A large amount of de-icing materialshad already been consumed in the Metropolitanarea and supplies had to be diverted from the southern parts of the country. Thus,the southern regions experienceda severe de-icing materials deficiency during the rest of the winter season. In general, the winter season in Koreacomprises four months(15th of Novemberthrough15th of March).Snow removal works on national highways, which comprise the major roadway network, are performed by regional offices. This consists of 18 units as shown in Figure 1, which areevenly distributed across the country (MOLIT, 2013).

Figure1. Official Region Boundariesand 18 Regional Offices in Korea

The Ministry of Land, Infrastructure and Transport (MOLIT) has identified the following three problems in snow removal works:

- Insufficient systematic scheme for snow removal works on national highways
- Inadequatede-icing materials,manpower and detailed snow removal operation strategies
- Absence of standard use criteriaof de-icing materials for snow removal works

To address these problems, in 2002, MOLIT established a national guide for snow and ice control in Korea(MOLIT, 2016).This guide clearly lays out theorganization of national snow removal works, level of service, and overall guidelines for public agencies.This was updated with new content to reflect improved snow removal techniques and changes in its policies in 2012.The most significant features arethe inclusion of standardapplication criteria for de-icing materials as well as description ofa specific way ofusing de-icing materials by road type. The updated manual describes these various aspects in detail and deals with properties of de-icing materials, chemical liquids, and pre-wetted salt.It also provides a method of estimating standard application of de-icing materials in order to improve field applicability.

Pre-wetting,which prevents the bonding of snow and ice to road surfaces, is thepredominantly usedmethod in South Korea.The compounds adhere to the road instead of bouncing off or being swept off by traffic. However, public agencies have pointed outthat in practice there areunsatisfactory aspects of using pre-wetting salt(Kim and Yang, 2017).Although critical components such as the amount of snowfall, number of snow removal working days, weather conditions, and traffic volume may vary by region, standard use criteria for de-icing materialswere not previously considered.Our study fills this gap. Estimating de-icing materialsuse on roadways is definitely a significant issue for regional offices in terms of developing winter maintenance strategiesand budget planning.Therefore, it is necessary to identifyhow the sprayed de-icing materials have performed using an equation indicated in the guide for snow and ice control in Korea.

In this study, weevaluated the differences between the estimated and the actual amountused based on statistical tests with historical data from 2011 to 2016 (MOLIT, 2011-2016). Based on the results of the analysis, we identify whether the amount of de-icing materials used in each of the regional officeswas excessive or insufficient.

II. REVIEW OF STANDARD APPLICATION CRITERIA ACROSS COUNTRIES

Many factors such as weather, geometric conditions, and travel speed of snow removal vehicles,affect the amount of de-icing materials used. Although U.S.states may have their own application criteria, the Federal Highway Administration and National Cooperative Highway Research Program (NCHRP) Report 526 suggests the relevant criteria presented in Table 1(Boselly, 2008, NCHRP 2004). However, the purpose of the NCHRP table is to show equivalent application rates of various de-icing chemicals for specific temperature ranges. This does not imply accepted or recommended rates. For example, one would never apply NaCl at 100 lbs/LM when the temperature is 5°F.

Table 1. Criteria of the Standard Application of De-icing Materials in the U.S.
(a) Suggested by AASHTO

Salt application rate guidelines							
Pre-wetted salt @ 12` side lane (assume 2-hr route)							
Surface Temperature	Fahrenheit	32-30	29-27	26-24	23-21	20-18	17-15
lbs of salt to be applied per lane mile	Heavy Frost, Mist, Light Snow	50	75	95	120	140	170
	Drizzle, Medium Snow 1/2” per hour	75	100	120	145	165	200
	Light Rain, Heavy Snow 1” per hour	100	140	182	250	300	350
Pre-wetted salt @ 12` wide lane (assume 3-hr route)							
Surface Temperature	Fahrenheit	32-30	29-27	26-24	23-21	20-18	17-15
lbs of salt to be applied per lane mile	Heavy Frost, Mist, Light Snow	75	115	145	180	210	255
	Drizzle, Medium Snow 1/2” per hour	115	150	180	220	250	300
	Light Rain, Heavy Snow 1” per hour	150	210	275	375	450	525

(b) Suggested by NCHRP

Temperature (℉)	NaCl		CaCl2		MgCl2		Kac		CMA	
	100%* Solid	23%* Liquid	90-92%* Solid	32%* Liquid	50%* Solid	27%* Liquid	100%* Solid	50%* Liquid	100%* Solid	25%* Liquid
	lb/LM	gal/LM	lb/LM	gal/LM	lb/LM	gal/LM	lb/LM	gal/LM	lb/LM	gal/LM
31.5	100	45	109	32	90	31	159	30	159	69
31	100	46	111	32	91	32	161	31	161	72
30.5	100	47	111	33	91	32	155	30	155	71
30	100	48	107	33	94	33	158	31	158	74
29	100	49	109	34	91	33	155	31	155	79
28	100	52	109	34	91	33	152	31	152	81
27	100	54	109	35	90	34	153	31	153	86
26	100	56	104	34	96	36	161	33	161	95
25	100	57	102	34	99	35	167	35	167	108
24	100	61	108	38	102	41	167	35	167	114
23	100	62	112	41	102	41	164	35	164	117
22	100	65	110	41	102	42	160	35	160	121
21	100	68	107	40	101	42	155	35	155	125
20	100	70	108	42	98	42	150	34	150	129
15	100	90	103	44	96	44	142	34	142	170
10	100	120	101	49	95	47	138	35	138	265
5	100	165	104	57	96	51	139	37	139	630

Switzerland in Europe employs salt as their prevailing de-icing agent. They have different application methods according to temperature specifically, dry salt, pre-wetting the salt and fixed auto salt application (MOLIT, 2002).The Hokkaido region of Japan is known for its high snowfall.The standard application criteria of de-icing materials are based on the road surface conditions(Hokkaido Development, 1996).When the air temperature is above -8℃, salt is used as the main de-icing material. For de-icing, approximately 30g/㎡ of use amount is applied while 15g/㎡ is used for pre-treatment. On the other hand, when the air temperature is below -8℃, both salt and sand are employed. In that case, a suitableapplication amount is in the range150~350g/㎡.
The standard application amount in Korea is comprehensively classified into "before snowfall", "during snowfall", and "during road freezing" as presented in Table 2(MOLIT, 2016).When pretreatmentis performed, the application is about 43g/㎡. This is equal to 0.15ton/km/lane. Table 2showsthe standard criteria for de-icing materials determined by snowfall and temperature. When traffic volumes are high, it is recommended that the entry one step higher be used (in terms of temperature).

Table2. Standard ApplicationCriteria forDe-icing Materials in South Korea

Snowfall		Temperature	Density (g/㎡)		
			Salt	Liquid	Amount
Pretreatment before snowfall		0 – -5 ℃	10	4.3	14.3
		-5℃ or lower	15	6.4	21.4
During snowfall	≤ 1㎝	0 – -5 ℃	10	4.3	14.3
		-5 – -10 ℃	15	6.4	21.4
		-10℃ or lower	20	8.6	28.6
	1 – 3㎝	0 – -5 ℃	15	6.4	21.4
		-5 – -10 ℃	20	8.6	28.6

		-10℃ or lower	25	10.7	35.7
	3 – 5cm	0 – -5 ℃	20	8.6	28.6
		-5 – -10 ℃	25	10.7	35.7
		-10℃ or lower	30	12.9	42.9
During freezing of roads		0 – -5 ℃	25	10.7	35.7
		-5℃ or lower	30	12.9	42.9

Every country has its own standard application criteria for de-icing materials according to weather, road surface, geometric conditions and amount of snowfall. However, the U.S. considers weather conditions, road surface temperature, traffic speed, and traffic volume very carefully. Conversely, specific temperature range and amount of snowfall are the primary criteria in South Korea.

III. METHODOLOGY

This study first compared the estimatedamount of de-icing materials based on the equation from the guide for snow and ice control in Korea and the actual use by region during the analysis period. Subsequently, a determination was made as to whether the amount of de-icing materials used in each of the regional officesappeared to be excessive or insufficient. The following three types of data were used as input forthe equation.

- Actual de-icing use amount by regional offices in the recent five years (from 2011 to 2016)
- Maintenance length of national highwaysfor snow removal works by regional offices
- Number of snow removal working days by regional offices

Two nonparametric statistical tests were used to quantitatively and statistically comparethe estimated amounts and the actual amounts by used by the regional offices. Nonparametric testsareideal when 1) assumptions of the parametric test cannot be satisfied,2) the number of collected data points is small, and 3) the distribution of the data cannot be assumed (Washington et al., 2003).The Kolmogorov Smirnov (K-S) test was employed first because it is suitable for analysis of the characteristics of the differences between two sample populations.This is based on the maximum difference, empirical and hypothetical cumulative distribution (Massey and Frank, 2012; Feller, 2012).Secondly,a Wilcoxon signed rank test was performed to evaluate the statistical adequacy of the distribution characteristics of the K-S test. This is useful for comparing two populations for which the observations are paired. As such, the test is a good alternative to the paired observations t-test in cases where the difference between the paired observations is not normally distributed (Hines et al., 2008). Figure 2 shows in detail the study flow.

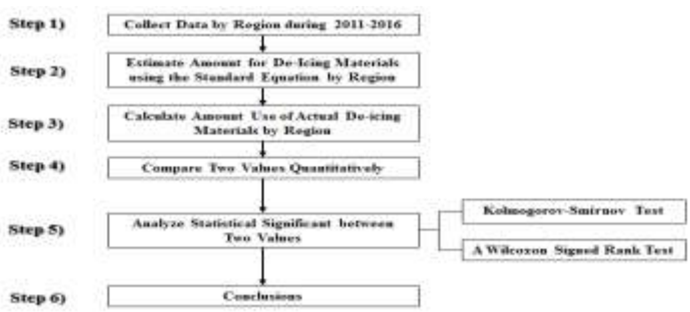

Figure2. Study Flow Details

There are many examplesin which the two testshave been applied to transportation problems.For example, Kathuria et al. (2016) employed observed and expected values of the bus lost time (BLT) to evaluate the capacity of bus rapid transit (BRT) stations before and after including BLT through the K-S and chi square testsJoshua et al.(2016) employed the global positioning system (GPS) data fromthe smartphones of 4,000 drivers collected from Quebec City, Canada for five years through the K-S test to analyze the correlation between traffic congestion and traffic flow in order to investigate a frequency of accidents and severity. The analysis results indicated that the severity of traffic accidents increased with frequency(Joshua et al, 2016).Smith et al. (2002)developed and employedtraffic volume forecasting models for two sites on Northern Virginia's Capital Beltway. Four models(historical average, time-series, neural network, and nonparametric regression models) were developed and tested for the freeway traffic flow forecasting problem. The final results revealed that the nonparametric regression model experienced significantly lower errors than the other models through a Wilcoxon signedrank test (Smith et al, 2002).Research by Shuyanemployed the applicability of support vector machine (SVM) ensemble for traffic incident detection. One nonparametric test, a Wilcoxon signed ranks testwas used to compare six combining schemes (Chen et al., 2009).

In summary, although no similar research can be found in previous studies, many studies have been conducted on verification and evaluation of significant distribution characteristics of variables in the transportationfield using the K-S test and theWilcoxon signed rank test.

IV. DATA DESCRIPTION

4.1 MAINTENANCE LENGTH OF NATIONAL HIGHWAYS FOR SNOW REMOVAL WORKS BY REGION

Figure 3(a) shows the maintenance lengths of national highways as of 2016. These data were obtained from the Korean National Statistics 2016.The longest maintenance length among two-lane highwaysisYoungnam followed by Honam, Gangwon, Chungcheong, and Metropolitan. For four-lane highways, the longest maintenance length is Youngnam, followed by Honam, Chungcheong, Metropolitan, and Gangwon. For the metropolitan region, there are more four-lane highways than two-lane highways whereas Gangwon has more two-lane highways than four-lane highways. Four-lane highways have recently been continuously increased. Owing to high standardization of highways and increased traffic volume.

4.2ACTUAL DE-ICING MATERIALS USE BY REGION

As shown in Figure3(b), the de-icing materials use amountduring the analysis period by region indicates thatGangwon used the most de-icing materials followed by Chungcheong, Honam, Metropolitan, and Youngnam. Historical data for actual de-icing materials use by region were collected from the Road Snow Removal Management System (RSMS) Database operated by MOLIT. The results imply that the regional use of de-icing materials (CaCl2 and salt) differs depending on regional weather conditions and the maintenance length of national highways.Honam used the most CaCl2, followed by Chungcheong, Gangwon, Metropolitan, and Youngnam whereas Gangwon used the most salt followed by Chungcheong, Honam, Metropolitan, and Youngnam. For Honam, the use of CaCl2, and salt has increased owing to frequent snowfalls as a result of severe adverseweatherchanges in recent years and also relatively long maintenance length. Gangwon and Chungcheong use more salt than CaCl2 fortwo reasons: (1) salt is three to four times less expensive than CaCl2 and (2) regional and local weather conditions frequently cause unexpected heavy snowfall.

4.3 NUMBER OF SNOW REMOVAL WORKING DAYS BY REGION

The average snow removal working days during the analysis period were as follows: Metropolitan 33 days, Gangwon 48 days, Chungcheong 23 days, Honam 23 days, and Youngnam 19 days. Gangwon had the largest average number of snow removal working days during the analysis period followed by Metropolitan, Chungcheong, Honam, and Youngnam. The results also imply that the number of snow removal working days differed depending on regional weather conditions and the maintenance length of national highways.These data also came from the RSMS Database operated by MOLIT.

Figure3(a). Maintenance Lengths of National Highways by Region

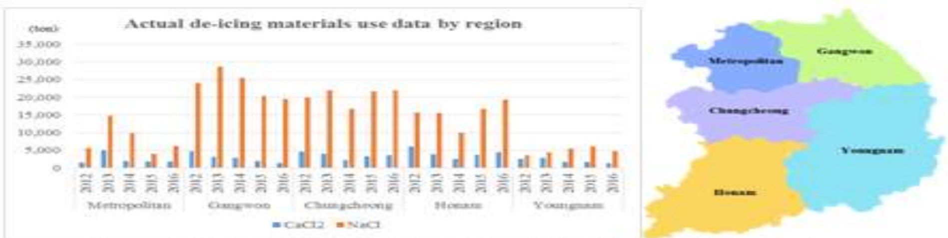

Figure3(b).Actual De-Icing Materials Use Data by Region

V. ESTIMATION AMOUNT OF DE-ICING MATERIALS BASED ON THE STANDARD EQUATION

Before estimating the amount of de-icing materials required using the standard equation, the de-icing materials application methods employed in Korea were examined. They can be categorized into three types solid application, liquid chemical, and salt pre-wetting.The first method refers to application of solid de-icing materials such as salt and CaCl2 before snow begins, in order to prevent road freezing and/or snow cover on the road. Currently, pre-wetting is the most widely usedmethod in Korea.This is the process of spraying de-icing salt with a solution of liquid chemical before they are applied to the roadway as part of the de-icing efforts. This accelerates the activation of the chemicals before they are applied to the road. Pre-wetting is not typically applied to roads before snow or ice accumulates. This is because salt is ineffective when temperatures fall below freezing as there is no moisture on the road. For pre-wetting, water and CaCl2should be mixed in a 7:3 proportions in the stirrer and then two chemicals are mixed at a ratio of 7:3.

In this study, we investigated pre-wetting of the salt proposed in the guide for snow and ice control in Korea to estimate a standard application amount of de-icing material by region. In that guide, the amount of chloride sprayed is 43g/㎡, which is the amount of chloride sprayed at a single time, which is 12.9g of a solution of liquid chemical (about 10㎖), and 30.1g of solid salt (3) When a 1km-long and 3.5m-wide lane is sprayed, about 0.15ton/km/lane (0.045 ton of a solution of liquid chemical (about 35ℓ) and 0.105 ton of solid salt) of de-icing material is sprayed. As a result, the salt use amount can be estimatedas0.105ton/1km/lanefor a single application when the lane width and the number of lanes are considered. For CaCl2, the standard application criteria are based on the liquid solution.This can be estimated at 0.018ton/1km/lane consideringthe manufacturers' information about the liquid CaCl2 and the equation presented in the guide for snow and ice control in Korea. In addition, both maintenance length and the number of snow removal working days by regional offices should be considered as important factors.

The guide for snow and ice control in Koreastates that the amount of de-icing agent appliedis estimated considering a one-time application amount, lane width, and the number of lanes. The actual amount, however, may be much more that the estimated amount. This is because the equation in the guide does not consider pretreatment before snowfall and additional amount due to serious road conditions. In general, pre-treatment is performed when the following conditions are met: 1) snow and/or sleet falls 2) the temperature is expected to be below 2℃, and 3) road freezing is expected owing to freezing rain. Because it is difficult to obtainactual data about both pretreatment and additional amount, theyare not included in the analysis.The road length for snow removal works in the guide indicates the number of lanes in one direction. Therefore, it is reasonable to double this to consider both directions. As shown in Figure 4, if a de-icing agent is usedon a two-lane road, then the road is effectively divided into three lanes.In this case, the de-icing agent is used only on the middle 1/3 portion, which is then scattered evenly to the entire road by means of vehicles travelling in both directions.

Considering the guide for snow and ice control in Korea, the equation can be shown as in Equation 1:

$$Estimated\ use\ amount = L_R \times D_S \times U_D (1)$$

Where,

L_R: Road maintenance length for snow removal works by region
D_S: Number of snow removal working days by region
U_D: Use amount of de-icing materials by region (ton/km/lane)

The comparison results between the amount estimated by Equation 1 and the actual useamount are presented in Table 3. First, the total estimatedamount of de-icing materials during the analysis period by regions was found to be about half of the actual amount. Dividing the resultsby de-icing materials shows that for the total amount of $CaCl_2$, the estimated amount was about 57% less than the actual use rate. Conversely, the estimated amount of salt was about 48% less than the actual use rate.Regionally, the comparison between the estimated and actual use of $CaCl_2$shows that Chungcheong and Honamhad the largest differences,whereasthose of Youngnam, Gangwon, and Metropolitan were relatively small. In addition, Gangwon and Chungcheonghad the largest differences, whereasthose of Metropolitan,Honam, and Youngnam were relatively small for salt. The estimatedamount of salt forYoungnam was more than the actualamount. This result reflects the weather conditions of Youngnam where snowfall islight.

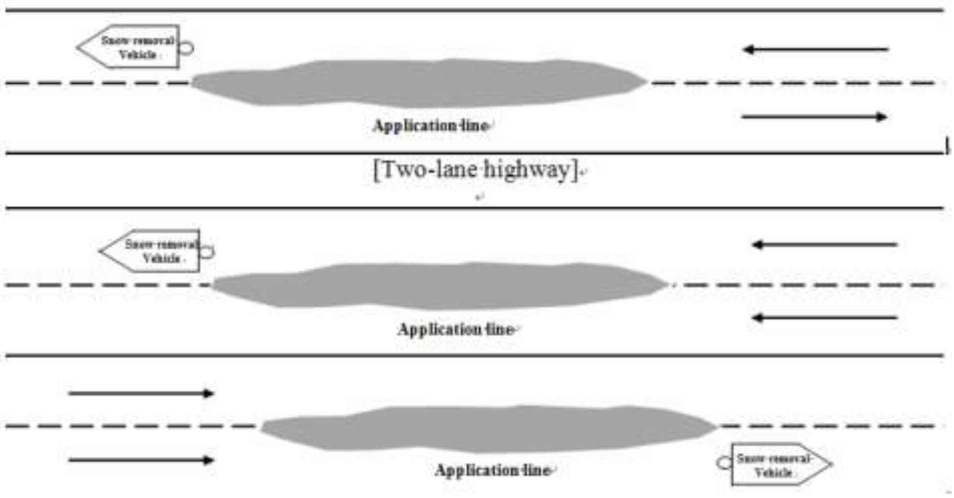

Figure4.De-icing Application Methods on Two- and Four-Lane Highways

Table 3.Comparison Results by Region

Region	Season	Maintenance length (km)	Snow removal working days (day)[1]	Actual use (ton)		Estimated (ton)	
				CaCl2	Salt	CaCl2	Salt
Metropolitan	2011-2012	1,589	50	1,603	5,656	1,430	8,340
	2012-2013	1,592	47	4,986	14,868	1,347	7,858
	2013-2014	1,567	21	1,972	9,791	592	3,456
	2014-2015	1,634	21	1,774	4,022	618	3,603
	2015-2016	1,661	26	1,778	6,178	777	4,533
Gangwon	2011-2012	1,722	48	4,684	24,052	1,488	8,681
	2012-2013	1,769	47	3,200	28,723	1,496	8,729
	2013-2014	1,755	51	2,843	25,516	1,611	9,396
	2014-2015	1,777	39	2,011	20,416	1,247	7,276
	2015-2016	1,796	54	1,454	19,422	1,746	10,184
Chungcheong	2011-2012	2,501	15	4,612	19,948	675	3,939
	2012-2013	2,495	32	3,997	21,999	1,437	8,382
	2013-2014	2,567	21	2,258	16,737	970	5,660
	2014-2015	2,647	22	3,305	21,695	1,048	6,114
	2015-2016	2,704	25	3,531	21,935	1,217	7,099
Honam	2011-2012	3,333	23	6,028	15,641	1,380	8,048
	2012-2013	3,359	20	3,943	15,480	1,209	7,053
	2013-2014	3,503	19	2,494	9,930	1,198	6,989
	2014-2015	3,541	24	3,736	16,694	1,530	8,923
	2015-2016	3,548	27	4,420	19,356	1,724	10,059
Youngnam	2011-2012	4,199	14	2,496	3,526	1,058	6,172
	2012-2013	4,250	19	2,892	4,469	1,453	8,479
	2013-2014	4,246	20	1,684	5,462	1,528	8,916
	2014-2015	4,449	21	1,657	6,027	1,682	9,810
	2015-2016	4,521	20	1,351	4,708	1,627	9,493

VI. STATISTICAL ANALYSIS

6.1 Kolmogorov-Smirnovtest (K-S test)

This test is one of the most useful and general nonparametric methods for comparing two samples (Bolen et al., 2014).As our objective is to compare estimatesfromthe predicted and actual amount, the

[1]Thisis the last recorded full-day work based on 24 hours. For example, if someone worked for 28hours, it would be recorded as 2 days.

distribution characteristics of the two values were analyzed through a K-S test of two independent samples. The X-axis in Figure5 refers to the cumulative years (0–5: Metropolitan, 6–10: Gangwon, 11–15: Chungcheong, 16–20: Honam, 21–25: Youngnam), whereasthe Y-axis represents the cumulative probability. When the actual and estimatedamount of $CaCl_2$are compared in Figure 5(a), Metropolitan, Gangwon, and Chungcheongappear to be similarwhile Honam and Youngnam show a large difference in distribution. Therefore, Honam and Youngnam used much more $CaCl_2$than the estimated amount as the frequency of snowfalls increased.

In Figure5(b), the difference in distribution of two values of saltis not very large in Metropolitan and Gangwon, whereas the difference in distribution is large in Chungcheong, Honam, and Youngnam. Thus, Chungcheong, Honam, and Youngnam used much more salt than the estimated amount as the frequency of snowfalls increased.

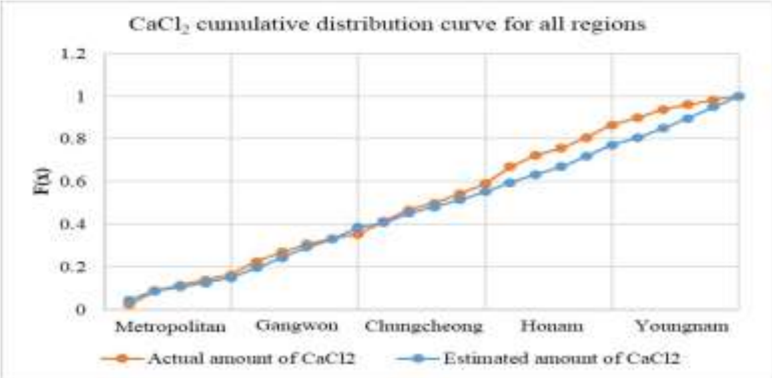

Figure5 (a). CaCl2 cumulative distribution curve for all regions

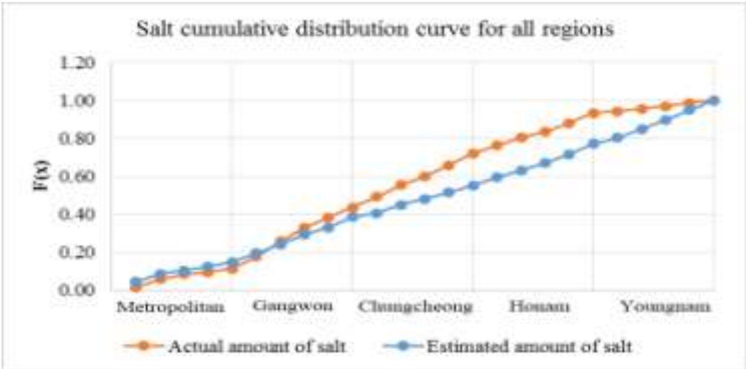

Figure5(b). Salt cumulative distribution curve for all regions

6.2 Wilcoxon Signed Rank Test

It is necessary to verify whether the difference between the estimated and actual use is statistically significant. A Wilcoxon signed rank test was employed to do this. The hypothesis was established using this test for paired samples at a 95 percent level of confidence.The null and alternative hypothesis was as follows:

H_o: Estimatedamount of de-icing material = Actual amount of de-icing material (No difference)

H_A: Estimated amount of de-icing material $\neq$ Actual amount of de-icing material (Different)

The test result for CaCl2 showed that Metropolitan, Chungcheong, and Honam were R-=0 (critical value R=0.05) as presented in Table 4(a).Therefore, the estimated and actual CaCl2 usedeffered. This was due to the characteristics of metropolitan areas,where traffic volume was relatively large compared with any other regions, increases in snowfalls caused by adverseweather in recent times, and increases in road length due to the PyeongChang Winter Olympic Games in 2018. The dominant reason is that metropolitan areas are urban areas and the traffic is heavy. Therefore, rapid snow removal has the highest priority. CaCl2 is knownto melt snow faster than salt. In contrast, Gangwon and Youngnam had no significant difference between the estimated and actual amount of CaCl2. Thus, the actual use of CaCl2 in the two regions was appropriate according to the estimatedamount of de-icing materials in Equation 1 Gangwon and Youngnam are suburban areas and thus traffic is relatively low. Therefore, they prefer salt to CaCl2.

The test result for salt showed that Gangwon, Chungcheong, and Honam were R-=0 (critical value R=0.05) as presented in Table 4(b).Therefore, the estimated and actual salt uses are different. As mentioned earlier, sustainable snow removal works are higher priority than rapid works in Gangwon. This is because salt is more persistent in melting snow than CaCl2. In the case of Chungcheong and Honam, a large difference in the usage of de-icing materials was revealed to be due to an increase in snowfalls caused by weather conditions, and inexperienced workers on the snow removal works teams. On the other hand, Metropolitan and Youngnam had no significant difference between the estimated and actual amount of salt. Thus, the actual use of salt in the two regions was estimated appropriately according to the standard use amount in Equation 1. The shaded areas in

Table4(a).Results of the Wilcoxon signed rank test for CaCl2

Region	Year	Signed rank	∑ R+	∑ R-
Metropolitan	2012	1	15	0
	2013	5		
	2014	4		
	2015	3		
	2016	2		
Gangwon	2012	5	14	1
	2013	4		
	2014	3		
	2015	2		
	2016	-1		
Chungcheong	2012	5	15	0
	2013	4		
	2014	1		
	2015	2		
	2016	3		
Honam	2012	5	15	0
	2013	4		
	2014	1		
	2015	2		
	2016	3		
Youngnam	2012	4	11	4
	2013	5		
	2014	2		
	2015	-1		
	2016	-3		

Table4(b). Results of a Wilcoxon signed rank test for salt

Region	Year	Signed rank	∑ R+	∑ R-
Metropolitan	2012	-3	12	3
	2013	5		
	2014	4		
	2015	1		
	2016	2		
Gangwon	2012	3	15	0
	2013	5		
	2014	4		
	2015	2		
	2016	1		
Chungcheong	2012	5	15	0
	2013	2		
	2014	1		
	2015	4		
	2016	3		
Honam	2012	2	15	0
	2013	4		
	2014	1		
	2015	3		
	2016	5		
Youngnam	2012	-1	0	15
	2013	-4		
	2014	-2		
	2015	-3		
	2016	-5		

VII. CONCLUSION

This study evaluated the difference in estimated and actual use of de-icing materials based ondata from 2011 to 2016 in South Korea. The analysis results were used to determine whether the amount of de-icing materials used in each of the regional officesexcessive or insufficient, as well as to careful considerthe need for more customized estimation considering regional properties.

First, a K-Stest was conducted to compare the distribution ofthe estimated and actual useamount forCaCl2. The results showed thatHonam and Youngnamhad a large difference during the analysisperiod. Next, aWilcoxon signed rank test was performed to verify the statistical significance of use amount differencesin the two regions. The results showed that Metropolitan, Chungcheong, and Honam's usewere statistically insignificant. Similarly, a K-Stest was also conducted to compare the distribution of the estimated and actual useforsalt.The test results showed that Gangwon, Chungcheong and Honam had a large difference in distribution during the analysis period. A subsequent Wilcoxon signed rank test showed that only Metropolitan and Youngnamwere not significant statistically.

In fact, Chungcheong and Honamgenerallydid not have much snowfall compared to other regions in the winter season. Snowfall, however, is currently increasing due to climate change in South Korea. Thisispresumed to have a great impact on the future use of de-icing agents. In addition, inexperience of snow removal personnel, lack of pretreatment strategies, and increasing vulnerable roadway sections for snow removal works on national highways also have an influence on the actual use of de-icing materials. The actual use of de-icing materials is largely dependent upon public agencies'understanding of snow removal works in regional offices. For example, in areas with high snowfall, de-icing materials are often used effectively in conjunction with snow removal works. Conversely, areas with low snowfall are mostly inexperienced. In addition, it is noted that the range of fluctuations in the use of de-icing materials can be large because of an increase in roadway length and civil complaints for the request of more rapid snow removal works. Thus, standard criteria for application rate of de-icing materials are able to play an important role in public agencies.Another important reason why these are required is that they are a key component of the overall budget for winter maintenance.As a result, it is important to evaluate the appropriateness of de-icing materials used by each region every year. It is also important to consider extending our evaluation methods to include additional variables for further research. Our study can be applied in a variety of other locations to identify mismatchesin material usage. Further, it is importantas specific decision-making based on suitable data analysis is essential as regards budget reduction and environmental impact.

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