RESEARCH ON DE-ICING CHEMICAL SCATTER PATTERNS / RUN-OFF QUANTITY

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1. Introduction

The application of de-icing chemicals onto roads is required to maintain winter traffic safety. The quantity of applied de-icing chemicals has increased year by year with prohibitions on the use of studded tires.

On the one hand there is some anxiety over the environmental impact of the de-icing chemicals, while at the same time there is demand for de-icing chemicals that ensure traffic safety.

In order to ascertain the mechanism, by which the de-icing chemicals affect the natural environment, this research examines de-icing chemical scatter patterns and the quantity of road run-off through experiments and a field survey. From the results, we have found that about 10% of the de-icing chemicals end up scattered on the side of the road and around 50% run off into gutters etc. Additionally, we found that the quantity of de-icing chemicals scattered on the ground at the side of the road dropped off sharply with distance from the edge of the roadway area. The function can be approximated based on the exponent of the distance from the edge of the roadway area, and overall, we found that over 50% was scattered within 5 meters of the edge of the roadway area.

2. Mechanism by which De-icing Chemicals Affect the Environment

The scattering and run-off process for de-icing chemicals applied to the road is illustrated in Figure 1. There, the balance of de-icing chemical scatter and run-off quantity is expressed as follows:

（Total quantity applied）＝（Quantity scattered）＋（Run off quantity）＋（Quantity remaining on road）＋（Quantity adhering to vehicles）

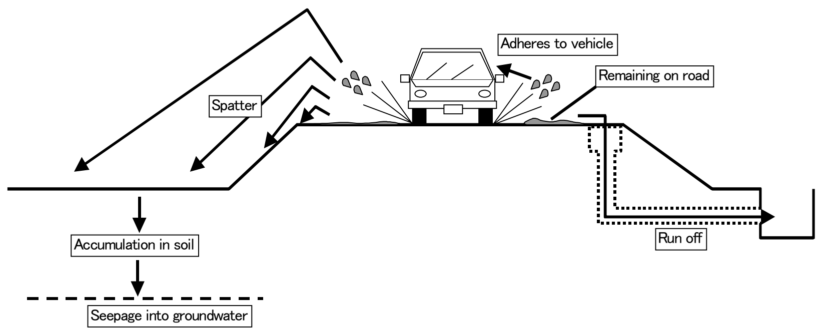


Figure 1: Process of de-icing chemical scatter and run-off.

In reality, the "quantity remaining on road" presented here, eventually becomes "quantity scattered", "run off quantity" or "quantity adhering to vehicles".

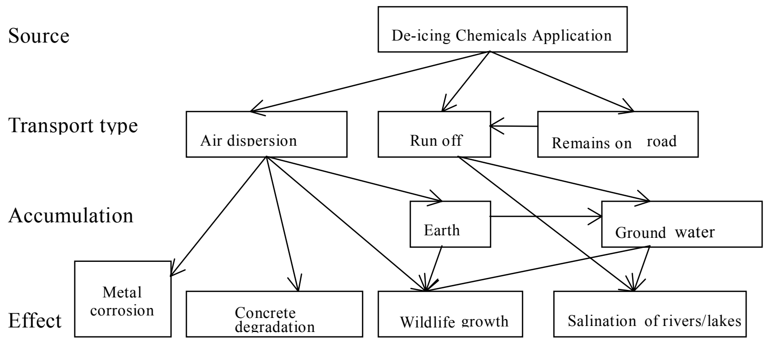


Figure 2: Envisioned effects of de-icing chemicals scattering and run-off.

On the one hand, the various effects envisioned from the scattering and run off of de-icing chemicals are shown in Figure 2. It is thought that the scattering and accumulation in the soil of de-icing chemicals due to vehicular traffic affects vegetation growth.

In explaining the effect mechanism of de-icing chemicals on the natural environment, we need to find how de-icing chemicals are scattered beyond the roadway, and grasp how chloride ions from de-icing chemicals accumulate in the earth. There is a need to determine whether chloride ion concentration has a negative impact on vegetation growth. Additionally, if this mechanism can be explained, new standards that limit the quantity and frequency of de-icing chemical applications based upon an environmental standpoint can be proposed in contrast to conventional standards made from the standpoint of road maintenance.

As a first step towards explaining the mechanism by which de-icing chemicals affect the natural environment, we aim to clarify the scatter patterns and run off quantities of de-icing chemicals applied to roads.

3. Outline of Experiments and Survey

Our research aims to grasp the quantities of run-off and scatter patterns for de-icing chemicals based on experiments and field surveys.

The major aim of the experiments was to determine the effects of speed, traffic volume, and vehicle type on de-icing chemical scatter patterns.

In addition, the field survey was undertaken with the primary goal of determining the amount of scattering and run-off for de-icing chemicals applied to the road under actual traffic conditions.

The experiments were carried out over a 10-day period from February 4th to the 13th of 2001 in Tomakomai City, Hokkaido, at the "Tomakomai Winter Test Track" using two types of collection equipment. 10 cases were examined to measure scatter quantity.

Field survey was undertaken on a national road over 70 day period from January 11th to March 21st, 2001 in the Hokuriku region. Collection devices and various sensors were installed along the cross section of the roadway and scatter quantity and run-off quantity measurements were taken.

Moreover, the current research does not take the quantity of de-icing chemicals adhering to vehicles into account.

4. De-icing Chemical Scattering Experiment

4.1 Experimental method

The de-icing chemicals applied to the road floats into the air through the effects of wind and vehicle traffic, from there, it eventually scatters on the surface of the ground. In the experiment, collection of the floating particles was via gauze laid on a wooden frame added to a steel tower. For the material scattered on the ground, collection was done by using containers laid along the cross section of the roadway. Wind direction, air speed, temperature, and other weather conditions were also measured.

The experimental procedure was as follows: ① On the night before the experiment, water was spread on to the test track inside of the test section shown in Figure 3. ② On the day of the test, collection equipment and gauze were installed, and in the test section shown in Figure 3, de-icing chemicals (NaCl) were applied. ③ A certain number of cars passed at a certain speed through the test section, and ④ the gauze and other equipment was collected .

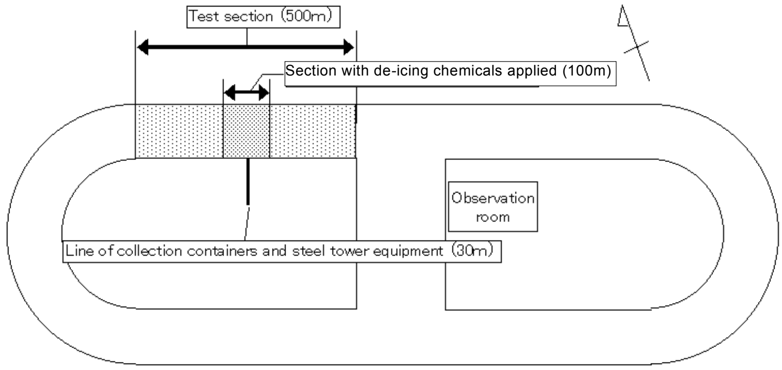


Figure 3: Test Track and Sections for De-icing chemicals Scatter Tests

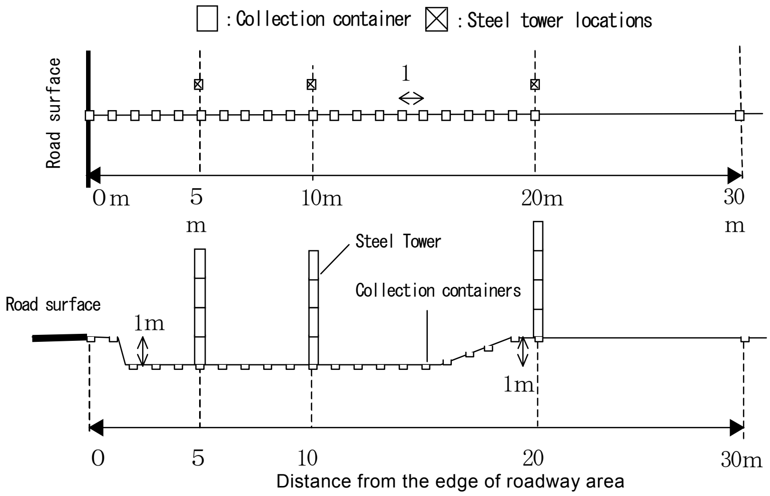


Figure 4: Locations of Towers and Collection Containers for Scattered De-icing

4.2 Measurement Location

In this experiment, without the disturbance of actual traffic, the Civil Engineering Research Institute of Hokkaido Development Bureau used test cars on the “Tomakomai Winter Test Track” to reproduce the scattering of de-icing chemicals. Containers and steel towers were set up downwind from the prevailing wind as illustrated in Figure 3. As illustrated in Figure 4, containers were placed at 1m intervals from 0 to 20m and then another was placed at 30m from the edge of roadway area. Steel towers were placed at the 5, 10, and 20m marks from the edge of roadway area. To these, gauze-laden wooden frames were added to the steel towers at one-meter intervals up to four meters from the surface of the ground.

4.3 Experimental Cases

The experimental cases are shown in Table 1. In the basic cases of 1 and 2, vehicles were of the small type, and speed was 40km/h, with 40 vehicles passing per hour. In cases 3 and 4, traffic volume was increased to 60 vehicles per hour. In cases 5, 6, 7, and 8, the speed of vehicles was increased to 60 km/h. Finally, in cases 9 and 10, the basic small vehicles were exchanged for large ones run at a frequency of 60 vehicles per hour. In total 10 cases of the experiment were performed.

Table 1 Cases of De-icing chemicals Scattering Experiments

Case	Vehicle Details		No. of Vehicles	Quantity of De-icing chemicals Applied	Weather Conditions	
	Type	Speed			Wind Speed	Prevailing Wind Direction
1	Small	40km/h	40/h	30g/m^2	4.4m/s	West
2	Small	40km/h	40/h	60g/m^2	1.5m/s	E-SE, N-NE
3	Small	40km/h	60/h	60g/m^2	1.6m/s	W-NW
4	Small	40km/h	60/h	120g/m^2	1.2m/s	N-NE
5	Small	60km/h	60/h	60g/m^2	1.6m/s	N, N-NE, W-NW
6	Small	60km/h	60/h	60g/m^2	3.4m/s	W-NW
7	Small	60km/h	60/h	120g/m^2	0.9m/s	N, N-NE
8	Small	60km/h	60/h	120g/m^2	2.2m/s	W-NW
9	Large	40km/h	60/h	60g/m^2	1.3m/s	NW
10	Large	40km/h	60/h	120g/m^2	1.1m/s	N

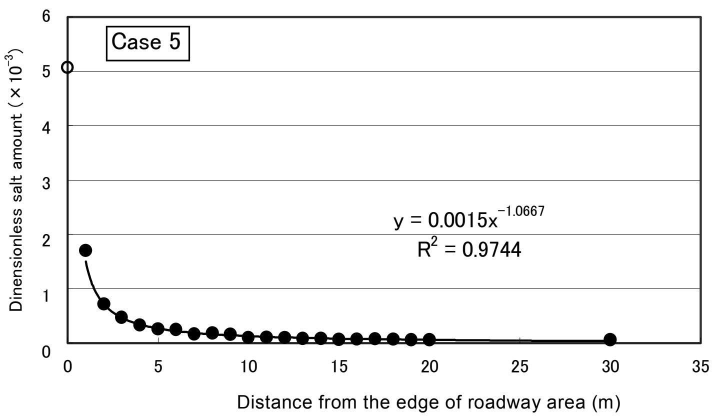
Decreased mobility on frozen winter roads was taken into account when determining the vehicle speed. De-icing chemicals were applied at a standard 30 g/m^2, and at a levels twice and four times that (60 g/m^2 and 120 g/m^2 respectively).

Furthermore, in our analysis, in order to exclude the effects of differing volumes of de-icing chemicals applied, the experimental results have been divided by the amount applied to make them dimensionless.

4.4 Experimental Results and Analysis

4.4.1 Quantity of Salt Scattered on the Ground

A sample of the relationship between the quantities of de-icing chemicals scattered on the ground (Quantity of Salt Scattered) and the distance from the edge of roadway area is shown in Figure 5. As shown, the salt quantity scattered on the ground tends to decrease sharply to correspond with an increase in distance from the edge of roadway area. The scattered quantity at a point of 5m from the edge of roadway area was 5% less than that at a point of the edge of roadway area. Also, at a distance of 5 to 30m from the edge of roadway area, the total quantity of salt scattered is between about 5 and 50% of total quantity from 0 to 5m of the edge of roadway area.



Note 1) The dimensionless salt amount is the measured salt amount (mg/m^2) divided by the amount of salt applied (mg/m^2).
Note 2) Excludes the approximate 0m location.

Figure 5: Relationship Between Distance From the Edge of Roadway Area and Dimensionless Salt Amount

Next, approximate

expressions for distance from the edge of roadway area and salt quantity are shown in Table 2. During this experiment we were able to obtain the best results for scattered salt quantity by approximating with the exponent of the distance from the edge of roadway area. Here the value of *coefficient a* for the approximate expression gives the value of the salt quantity scattered on the ground and the value of *exponent b* for the expression gives the rate of decrease over distance. Also, the data from cases 1 and 6 was excluded from the analysis because, compared with other cases, there was a strong wind parallel to the road which caused great data fluctuations.

Below, the relationship between the sizes of the coefficient and exponent, the volume of vehicles, their speed, and their type is explained.

(1) Relationship to the Traffic Volume

When the basic case (case 2), is compared to those where only the traffic volume was increased (cases 3 and 4), it is apparent that with an increase in traffic volume, the *exponent b* becomes smaller and the rate of decrease over distance becomes larger (Figure

Table 2: Relationship of *Coefficient a* and *Exponent b* for the Approximate Expression of Dimensionless Salt Amount

Case	$y = ax^b$ x: Distance from the edge of roadway area y: Dimensionless salt amount		
	Coefficient a	Exponent b	r^2 value
2	0.00011	−0.2688	0.5476
3	0.00021	−0.7169	0.4982
4	0.00007	−0.5459	0.7878
5	0.00151	−1.0667	0.9744
7	0.11626	−2.661	0.8914
8	0.00034	−0.4957	0.2919
9	0.01034	−1.544	0.9844
10	0.00976	−1.5031	0.9578

Note 1) Excludes the approximate 0m location.
Note 2) The dimensionless salt amount is the measured salt amount (mg/m2) divided by the amount of salt applied (mg/m2).

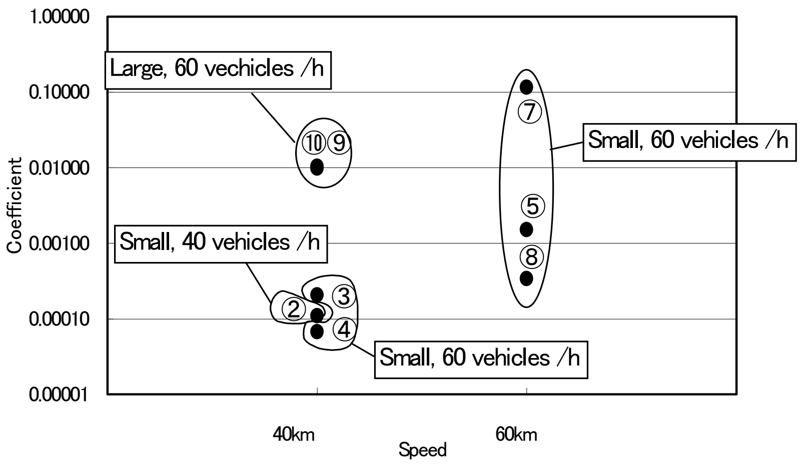


Figure 6: Relationship of *Coefficient a* to Traffic Volume and Speed.

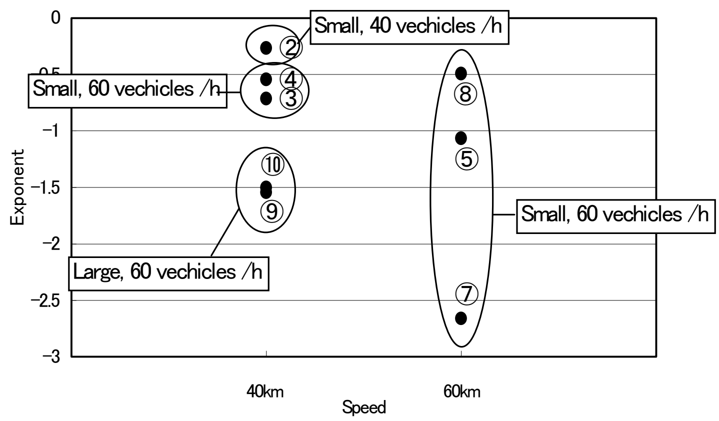
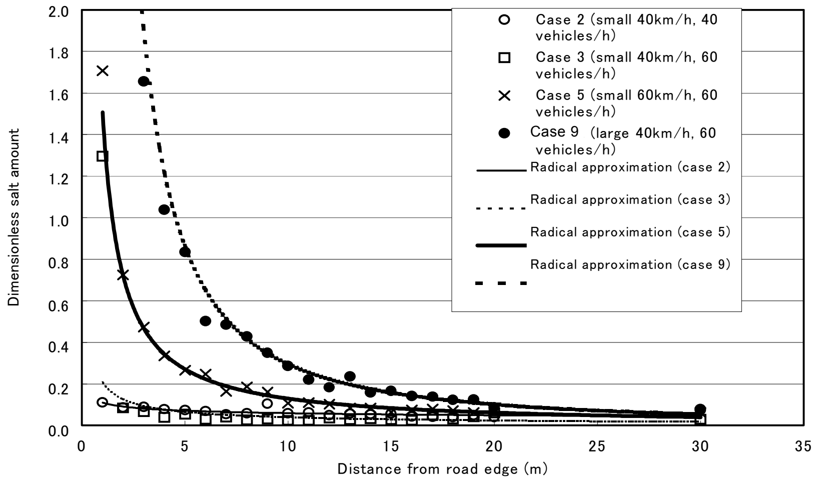


Figure 7: Relationship of *Exponent b* to Traffic Volume and Speed.

6 and 8). Here, as the traffic volume increases, scatter frequency increases due to water spatter, and the quantity of salt in the vicinity of the road becomes larger. It is thought that this is due to an increase in rate of decrease over distance.



Note 1) The dimensionless salt am Distance from the edge of roadway area (m) of salt applied (mg/m²).
Note 2) Excludes the approximate

Figure 8: Relationship of Dimensionless Salt Amount and Distance From Edge of Roadway Area (Example)

(2) Relationship to Traffic Speed

From a comparison of cases 3 and 4 with 5, 7 and 8, where the speed was increased, it was found that with increases in speed, the *exponent b* becomes smaller and the *coefficient a* larger (See Figures 6, 7, and 8). In other words, as the speed increases, the quantity of scattered salt at the edge of the roadway area increases, but after a quick drop in the salt quantity just as we leave the edge of roadway area, the value of salt becomes relatively uniform as we move further away. It is thought that this is because as speed increases, the quantity of salt scattered on the ground increases due to scattering by water spatter from vehicles, and that this effect is present up to a certain distance from the edge of the roadway area (See Figure 8).

(3) Relationship to Vehicle Type

When comparing cases 9 and 10 where large vehicles were used, and cases 3 and 4 to similar traffic speed and volume conditions, it was found that with increased vehicle size, the *exponent b* decreased and the *coefficient a* increased in value (See Figures 6,7, and 8). It is thought that increased vehicle size causes the quantity of salt scattered on the ground to increase due to scattering in the air, and that this effect is present up to a certain distance from the edge of the roadway area.

5. Field Survey

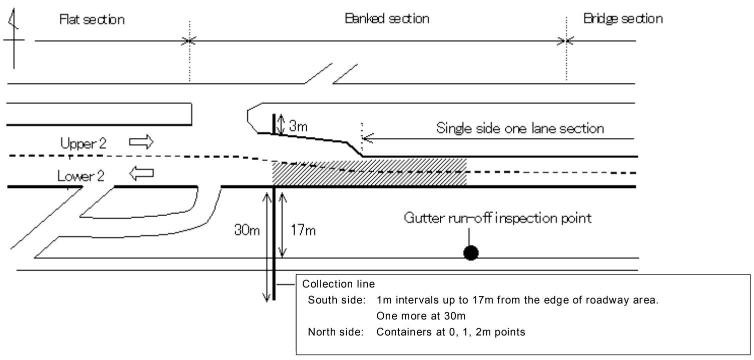
5.1 Survey Method

De-icing chemicals applied to the surface of an actual road is either scattered on the ground through the effects of wind and passing cars, or it becomes mixed with removed snow with which it flows away through the road's gutters etc.

In this study, material scattered on the ground is measured by containers placed along the cross section of the roadway. To measure that which flows into the gutters, electrical conductivity and water level sensors were installed into triangular weirs. Wind direction, wind speed, temperature etc. were also measured.

Measurement was carried out over a 70 day period from January 11th, 2001 to March 21st. Containers were collected every 7 days and their chloride ion concentration was analyzed in the lab. Also, the values of the electrical conductivity rate and water level were recorded automatically by a data logger at one hour intervals. Additionally, while collecting the containers, discharged water from the gutters was sampled, and run-off quantity, chloride ion concentration, electrical conductivity rate, and pH were measured.

Additionally, the quantity of applied de-icing chemicals （NaCl） was calculated from de-icing chemicals application records by the office or branch in charge of the road.



Note 1) Section where de-icing chemicals are applied:
Approx 1.6km for both upper and lower lanes (Amount applied: 20g/m^2, Total upper and lower application width is 12m.

Note 2) The hatched area is the road run off catchment area (approx. 200m)

Figure 9: Layout of Survey Field

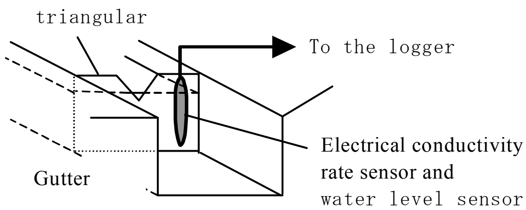


Figure 10: Sensor Equipment

5.2 Area under Survey

The area chosen for survey was a national road to which de-icing chemicals are applied in winter and which could accommodate the placing of collection containers downwind from the prevailing wind within a 30m range from the edge of the roadway area.

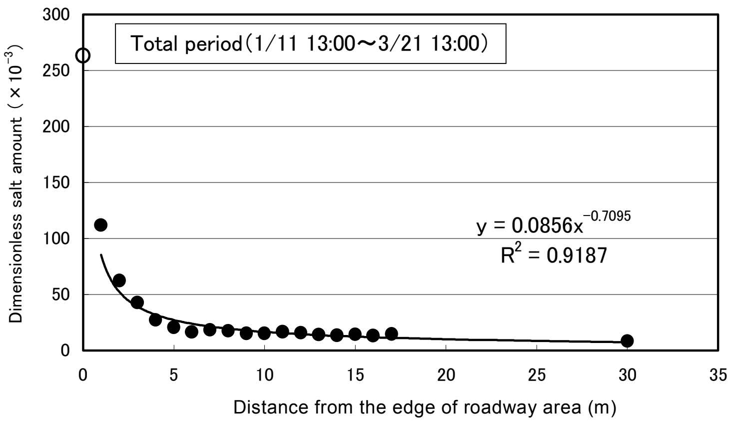
The collection containers were located up to 30m away from the edge of roadway area as shown in Figure 9. Placement was at 1m intervals from the edge of roadway area to about 17m away on the lower side and at 1m intervals up to 3 meters on the upper side. Due to consideration of data variances at some locations, two containers were placed at each collection point.

Electrical conductivity rate sensors and water level sensors were also set up at locations where road run-off through gutters was collected as shown in Figure 10.

5.3 Survey Results and Analysis

5.3.1 Quantity of Salt Scattered on the Ground

The relationship between the quantity of de-icing chemicals from the road to scatter on the ground (Quantity of Salt Scattered) and the distance from the road is shown in Figure 11. The vertical axis of Figure 11 is the total quantity of salt per square meter measured to scatter on the ground over the entire measurement period divided by the



Note 1) The dimensionless salt amount is the measured salt amount(mg/m^2) divided by the amount of salt applied(m

Note 2) Excludes the approximate 0m location.

Figure 11: Relationship of Dimensionless Salt Amount to Distance from Edge of Roadway Area

total quantity applied. Figure 11 shows that the quantity of salt scattered on the ground has a tendency to drop off with distance just as shown in the experiment at "Tomakomai Winter Test Track". Compared with a point at the edge of the roadway area, the quantity of salt scattered on the ground at 5m was about 8%. The quantity of salt scattered at points 5 to 30m from the edge of the roadway area was about 90% of the total from 0 to 5m.

The coefficient in Figure 11 is 0.0856 and the exponent is –0.71. Below is an explanation of factors affecting the *coefficient a* and the *exponent b*.

(1) *Coefficient a*

Coefficient a represents the quantity of salt scattered on the ground. When compared, *coefficient a* from the field survey is shown to be larger than that from the experiment. This is shown in Table 3 and is thought to be the result of differing traffic volumes and speeds on the track and actual roads. Here the *coefficient a* for the actual road is over 100 times larger than the coefficient for the small vehicles test, even though the small vehicle traffic volume on the actual road was approximately 31-46 times larger than the test course's 240 to 360 vehicles over a six hour period. At the same time, the *coefficient a* for the actual road was 8 times larger than for the experiment using large vehicles; however, the volume of large vehicles on the actual road was about 10 times that of the test's 360 vehicles over six hours.

As for the quantity of salt scattered on the ground, if we assume that it is affected by water spatter from passing vehicles, it is difficult to imagine that the actual road's coefficient would be any more than a multiple of the experiment coefficient as determined by the difference in traffic volume. Because of this, it is thought that the traffic volume and speed of large vehicles on the actual road had a major effect on the coefficient.

Table 3: Traffic Conditions for Field Survey Sites

Down Side			Up Side			Total	
Traffic Quantity		Traffic Speed	Traffic Quantity		Traffic Speed	Traffic Quantity	
Small (Vehicles/day)	Large (Vehicles/day)	(km/h)	Small (Vehicles/day)	Large (Vehicles/day)	(km/h)	Small (Vehicles/day)	Large (Vehicles/day)
5,669	1,753	57.7	5,439	1,672	55.8	11,108	3,425

(2) *Exponent b*

Exponent b expresses the size of the drop off ratio over distance. The value of *exponent b* was shown to be the same in both the experiment and field surveys.

Here the *exponent b* for the actual road is larger than that for the large vehicle test. In other words, the drop off over distance is less. This is thought to be the result of the large vehicles on the actual road moving faster than those in the test which causes the quantity of salt scattered on the ground to be spread over a greater range from the edge of roadway area via increased water spatter.

The amount of salt scattered seems to have been greatly affected by the increase in traffic volume and speed of large vehicles on the actual road.

5.3.2 Balancing the Quantity of De-icing chemicals Applied

Table 4 shows the relationships between total salt scattered on the ground, quantity flowing into gutters mixed with removed snow etc. (run-off salt quantity), and the total quantity of salt applied. Of salt applied to the road, about 6% ends up along the lower side of the road, and approximately 53% runs off into gutters.

Table 4　Relationship of Applied Quantity to Run-off Quantity and Salt Quantity Scattered on the Ground.

Run-off due to Splatter			Run-off from Gutters		
Quantity Applied (g/m)	Salt Quantity Scattered on the Ground (g/m)	Proportion (%)	Quantity Applied (g/m)	Salt Quantity Scattered on the Ground (g/m)	Proportion (%)
14,400	871	6.0	10,566	5,629	53.3

Note 1)　The difference between "run-off due to splatter" and "run-off from gutters" is that the measurement of run-off from gutters excludes the value for "quantity applied" while no measurements were being made.

Note 2)　The "salt quantity deposited the ground" is the quantity deposited the ground within a 30m range of the upper edge of the road

Note 3)　The "quantity applied" in "run-off from gutters" is the quantity applied over the gutter's catchment area divided by the length of the road

6. The Relationship of Quantity on Scattered the Ground to *Coefficient a* and *Exponent b*

If the quantity of salt expressed as a function of the distance from the edge of the roadway area($Y=aX^b$) is integrated with distance, the total quantity of salt scattered at any point can be calculated. If the dimensionless quantity made by dividing the quantity of salt scattered on the ground by the quantity of salt applied (dimensionless salt amount) is integrated with distance, the ratio of total applied salt to total salt scattered on the ground can be calculated (referred to below as "scatter ratio")

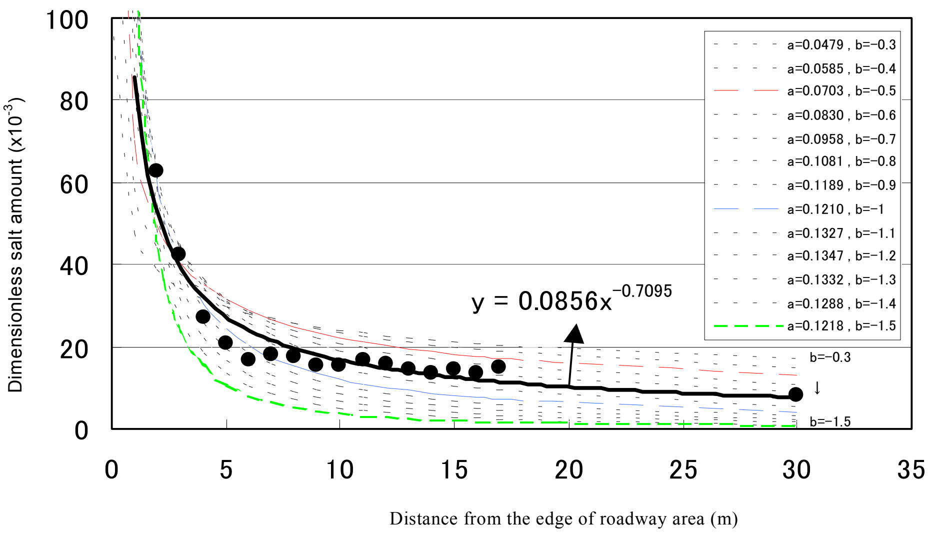


Figure 12: Relationship of Dimensionless Salt Amount and Distance from edge of Roadway Area with *Coefficient a* and *Exponent b*

According to the results of this experiment and field survey, with the scatter ratio being approximately 6%(See Table 4), and the value of *exponent b* being between –1.5 and –0.3, the relationship between the distance from the edge of the roadway area and the dimensionless salt amount is as shown in Figure 12. As shown, if the dimensionless salt amount for any point is multiplied by the quantity of salt applied, the scattered salt quantity for that point can be calculated.

If the quantity of salt which causes chloride ion accumulation in the soil at concentrations sufficient to inhibit growth in plants is determined (growth inhibiting salt quantity), determination of whether growth inhibition in plants will occur or not can be made through comparison with the scattered salt quantity.

Also, if the growth inhibiting salt quantity is determined, based on standard de-icing chemical application quantities and each point's dimensionless salt amount, the frequency at which salt can be applied without inhibiting plant growth can be suggested (see the following equation).

$$aX_1^{\ b} \times F \times Sd_{std} \leqq Ig_{crt}$$

$aX_1^{\ b}$: Dimensionless salt amount at a point X_1 from the edge of roadway area
F : Frequency of de-icing chemical applications Sd_{std} : Standard de-icing chemical application quantity
Ig_{crt} : Growth inhibiting salt quantity

However, to obtain an accurate scattered salt quantity, it is necessary to determine the relationship between the scatter ratio, traffic conditions, and weather conditions to *exponent b* by using data accumulated during the field survey and experiments.

7. Conclusion

From the current experiments and the field survey, the following was learned:

- The relationship between the quantity of salt applied and the quantity of salt spattered can be approximated as an exponential function of the distance from the edge of the road ($Y=aX^b$).
- According to the experiments, *coefficient a* and *exponent b* of the exponential function are affected by traffic volume, traffic speed and vehicle type.
- As a rule, as the traffic volume increases, *exponent b* becomes smaller, and *coefficient a* grows larger. With an increase in vehicle size *exponent b* becomes smaller, and *coefficient a* grows larger.
- During the field survey, it was observed that *coefficient a* and *exponent b* are affected more by the traffic volume and speed of large vehicles than by that of small vehicles.

To build on this, if in future experiments and field surveys, the relationship between the exponential function's *coefficient a* and *exponent b,* to traffic and weather conditions can be determined, the quantity of salt spattered corresponding to distance from the edge of the roadway area will be clear.

8. Issues

Through field surveys and experiments this study has clarified the scatter patterns and run-off levels of de-icing chemicals. However, with data from only one field survey carried out in the last winter period, and with just 10 experimental cases, there is a need to accumulate more data for cases where factors such as the road, traffic and weather conditions vary. Also, in order to clarify the mechanism by which the natural environment is affected, there is a need to collect data on the salt tolerance of related vegetation.

In the future, as we collect this sort of data as much as possible, we aim to establish a method of de-icing chemical application that does not affect the natural environment.

Acknowledgements:

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