

Development of a Cost Management Method for Road Snow Removal in Cold, Snowy Regions

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Abstract : The reduction of snow removal expenditures is a pressing need for governments in Japan. Reducing snow removal expenditures at the national government level requires the following: 1) analysis of the cost structure, 2) development of a method for comparing costs among regions, and 3) development of cost reduction standards.

We studied methods for objectively determining the cost effectiveness of snow removal, toward inter-regional comparison that has been regarded as difficult. To this end, we developed a model uses a linear regression line of "unit cost of snow removal" (UCSR) that is based on the relationship between snow removal costs and cumulative snowfall. This study presents how the model has been developed and discusses its applicability by using actual snow removal records. We also examine applicability of the model when the data from which the model is derived include those for an extremely snowy year and an unusually less snowy year.

Key Words: *snow removal, reduction of expenditures, budget, UCSR, cost reduction standards*

1. INTRODUCTION

Many of Japan's large cities are in snowy regions, and snow removal plays an important role

in securing smooth road traffic in winter (FIGURE 1). Studies have addressed various aspects of road snow removal. As the first study in Japan on the economic benefit of road snow removal, Igarashi *et al.* measured that benefit. They further suggested a method for deploying snow removal machinery such as to minimize the “total snow removal cost.” Sakai *et al.* calculated the benefit of snow removal by dividing the mitigation of economic loss achieved by snow removal by the snow removal cost.

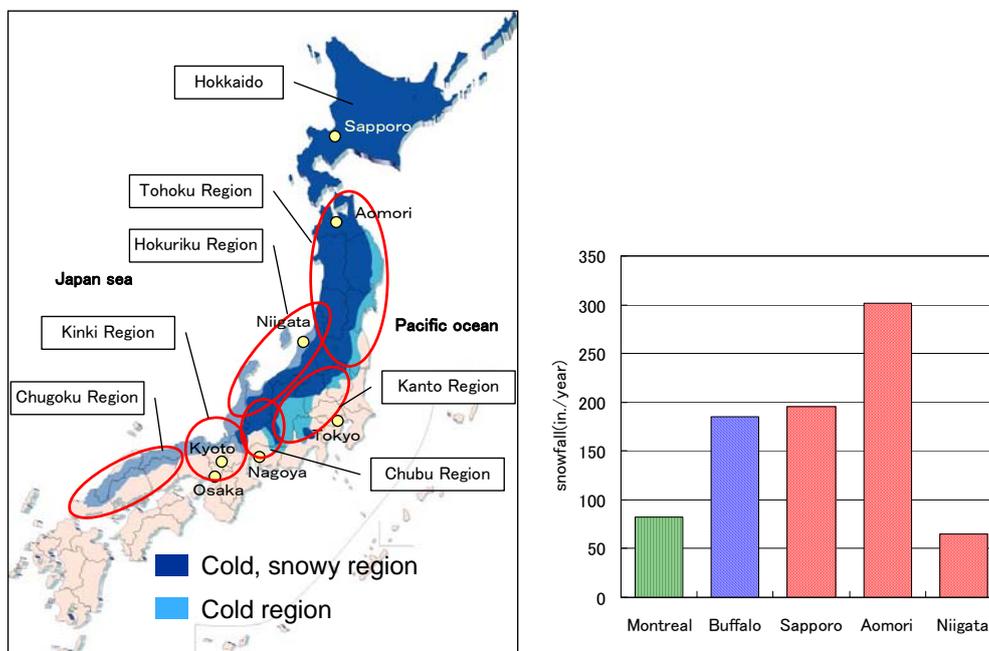


Figure 1 Snowfall of major cities in Japan and overseas

There are recent studies that focus on beneficiaries’ awareness for the service level of snow removal to find a solution for cost reduction. From this viewpoint, issues including the demand for snow removal, residents’ willingness to pay and residents’ satisfaction levels for snow removal have been discussed.

Most of these studies on snow removal addressed economic benefits, or used questionnaire surveys to address public involvement or customer satisfaction. Very few in-depth studies have addressed the cost structure of snow removal by the Japanese government.

As for the cost reduction efforts for infrastructure management including snow removal in the U.S.A. and other countries, Baroga, E.V. proposed to measure performance-based service levels to use it for budget and resource allocations; and Lindsey, R.K.*et al.* focused work conditions including geography and climate that are different by work site to realize efficient resource allocation for snow removal. Other than those for snow removal, efforts including the bridge management system have been made to optimize budget allocation for infrastructure management. However, there seem to be few studies on a model that enables efficient snow removal budget and resource allocations on the basis of cost structure analyses as well as of inter-regional comparisons of the time-series data of snow removal costs.

To reduce snow removal cost at the national level, it is necessary to 1) analyze the structure of snow removal cost, 2) develop a method for inter-regional comparison of such cost, and 3) set standards for cost reduction. Inter-regional comparison of snow removal cost has been regarded as very complicated, because the cost varies with snowfall amount, air temperature,

snow texture and other natural phenomena; with the degree of development (e.g., urbanized vs. rural); and with the demand for snow control, including how accustomed the road users are to snowfall. This paper reports on the development of an objective evaluation method to estimate snow removal cost by clarifying the relationship between snow removal cost and cumulative snowfall, both of which are relatively easy to obtain, and on how inter-regional comparison of snow removal costs is possible by using the developed estimation method. The applicability of the model is also verified by comparing the snow removal costs estimated by the model with the actual snow removal costs expended. Further, the applicability of the model when the snow removal data from which the model is derived include those for an extremely snowy year and an unusually less snowy year is examined.

The winter of 2005-2006 (FY 2005) was the first in 43 years with extremely heavy snowfall in Japan, and the Japan Meteorological Agency designated it “the Heavy Snowfall of 2006” (FY2005). Prefectural and municipal snow removal budgets were exhausted, and the Ministry of Land, Infrastructure and Transport (MLIT) responded to local governments’ requests by increasing snow removal subsidies. On that occasion, MLIT was asked to objectively estimate snow removal costs by using data such as snowfall and length of road designated for snow removal. However, no method for such estimation had been established.

Then, MLIT has adopted the method, a unit cost of snow removal (UCSR) line model (hereinafter: UCSR-line model) introduced in this study for allocating public snow removal budget since FY 2005.

2. BUDGETARY SYSTEM FOR SNOW REMOVAL IN JAPAN

Out of Japan’s total road length of 1.2 mil. km (744 thou. miles), municipal roads account for about 84%. The length of national roads under the direct control of the national government accounts for a mere 1.9% of the total. The length of roads in the cold, snowy areas that account for about 60% of Japan’s land area is about 41.6 thou. km (25.79 thou. miles). The national government fully finances snow removal for national highways, including expressways, and partially subsidizes snow removal for national highways under the control of prefectures and prefectural roads in areas designated as snowy and cold by *The Special Measures Law for Ensuring Road Traffic in Snowy and Cold Areas (The SCA Law)* (Figure 2).

The national government covers snow removal costs for nationally managed national highways. The national government subsidizes snow removal costs for prefecturally managed national highways and prefectural roads in areas designated as snowy and cold by *The SCA Law*. The law states that the national government shall subsidize prefectures for two thirds of the cost of snow removal, with the prefecture covering the remaining third. At present, the national government’s subsidy for roads in areas that are designated as snowy and cold by the law amounts to about 70 billion yen (\$583 million (\$1/ ¥120), FY 2007). National revenues for this subsidy include those from the national gas tax, the automobile tonnage tax and the automobile acquisition tax. Those revenues, whose disbursement is limited to road-related projects, amount to about 5.6 trillion yen (\$47 billion, FY 2007).

Each prefecture’s snow removal costs are financed from the prefectural general account and the prefectural special account. The revenue sources for the prefectural special account includes the light oil wholesale tax, whose disbursement is limited to road-related projects.

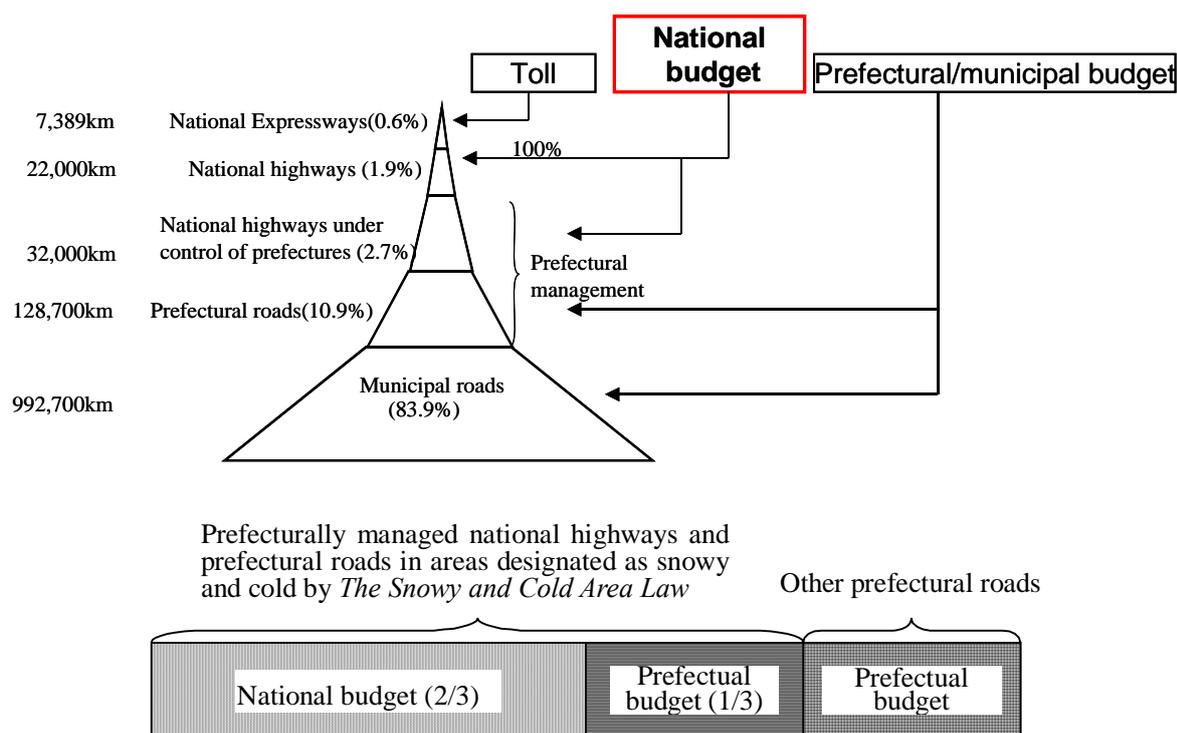


Figure 2 Roads in Japan and their budgets

3.UCSR-LINE MODEL DERIVED BY THE RELATIONSHIP BETWEEN CUMULATIVE SNOWFALL AND SNOW REMOVAL COST

How the UCSR-line model has been developed is introduced here.

Generally, the snow removal cost for roads (hereinafter: snow removal cost) consists of the costs for 1) roadway snow removal, 2) sidewalk snow removal, 3) anti-freezing agent application and 4) snow hauling and miscellaneous.

Various explanatory variables can be considered for these costs. The variables include road length, road width, snowfall amount, road surface condition, snow removal frequency and amount of hauled snow.

However, obtaining all these data is quite difficult; consequently, clarifying the relationship between all the variables and the snow removal costs is impractical.

Thus, we tried to calculate snow removal cost by using data such as cumulative snowfall and length of road designated for snow removal, which are relatively easy to obtain.

Two kinds of data represent the amount of snowfall: snowfall per snowfall event, and annual snowfall. Snow removal deployment is launched in response to each day's snowfall. When we examine the cost for snow removal, it is appropriate to use cumulative snowfall.

The structure of snow removal cost is complicated, as shown above. The cost varies depending on the snowfall, as expressed in the following equation.

$$p=f(x) \quad (1)$$

Where, p is snow removal cost and x is cumulative snowfall.

This function is expected to plot as an upward-sloping line, because snow removal cost increases with increases in cumulative snowfall. The total snow removal cost, however,

includes costs that are independent of snowfall amount, including the cost for anti-freezing agent application and fixed operating costs. The function has terms that change and terms that do not change (constant terms) with changes in cumulative snowfall.

If we assume that a linear regression model can describe the relationship between snow removal cost and cumulative snowfall, then the snow removal cost can be expressed by Equation 2.

$$p=f(x)=ax+b \quad (2)$$

Where p is snow removal cost, x is cumulative snowfall, a is a coefficient expressing snow removal cost per centimeter of cumulative snowfall and b is a coefficient of snow removal cost that does not depend on the cumulative snowfall of the area where the snow removal is conducted. The snow removal cost expressed in the above equation includes the cost for hauling snow, which increases in stepwise increments with increases in cumulative snowfall (FIGURE 3(2)).

The snow removal cost includes a cost that changes in stepwise increments, and it is thought that the line that expresses the relationship between snow removal cost and cumulative snowfall is not a simple line. However, when the cost for hauling snow does not dominate the total snow removal cost, it is considered that a linear approximation can describe the relationship between snow removal cost and cumulative snowfall (FIGURE 3(3)).

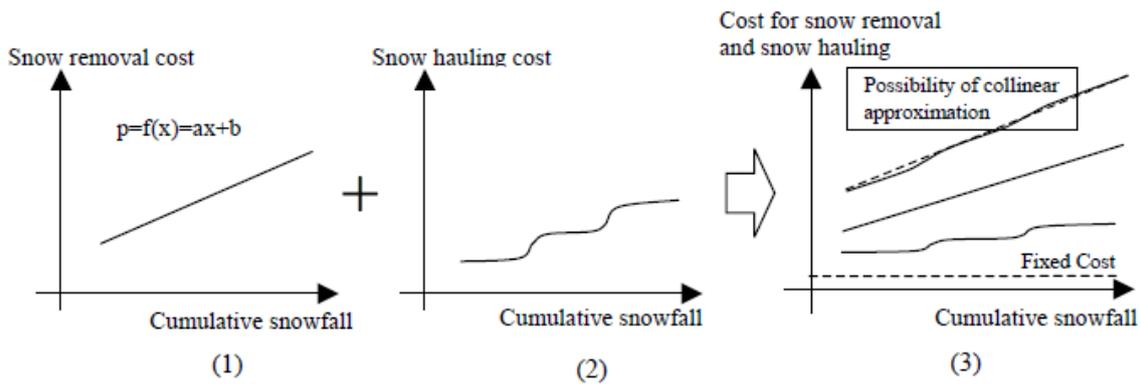


Figure 3 Costs for snow removal and snow hauling vs. cumulative snowfall

Next, we examine the relationship between the UCSR and cumulative snowfall.

The UCSR, which is obtained by dividing the annual snow removal cost (p , (million yen)) by the length of road with snow removal (L (km)) and cumulative snowfall (x (cm)), is expressed as follows.

$$y=p/L/x \quad (3)$$

The length of road with snow removal is the length of routes that are designated as those whose snow removal costs are shared by the national and prefectural governments under *The SCA Law*. The road length can be treated as a constant because it does not change with changes in cumulative snowfall (x).

From Equations (2) and (3), we obtain:

$$y=f(x)/L/x \\ = (ax+b)/L/x = (a+b/x)/L \quad (4)$$

$$= \frac{b}{L} * \frac{1}{x} + \frac{a}{L} \quad (4 \text{ i})$$

Where $\frac{b}{L} = \alpha$, $\frac{a}{L} = \gamma$

Equation (4 i) can be rewritten as:

$$\alpha x^{-1} + \gamma \quad (4 \text{ ii})$$

Generally, a power function is expressed as

$$y = \alpha x^{\beta} + \gamma \quad (5)$$

When β is -1, Equation (4 i) can be rewritten as Equation (5). The UCSR can be expressed as a power function of cumulative snowfall.

In Equation (5), γ is not dependent on cumulative snowfall (x), and when β is negative, the UCSR (y) gradually approaches γ as x increases.

The work time and cost required to remove 5 cm of snowfall do not differ much from those required to remove 6 cm of snowfall. The work time required to remove 10 cm of snowfall is longer than that to remove 5 cm of snowfall, but not twice as long. From this example, it can be thought that the UCSR decreases with increases in cumulative snowfall.

In other words, the snow removal cost includes costs that are not dependent on the cumulative snowfall, which means that the UCSR cannot fall below a certain value, and the UCSR has a negative correlation with the cumulative snowfall.

In light of this, UCSR plots as a downward-sloping regression line that represents the negative correlation between the variables, with cumulative snowfall on the x axis and UCSR on the y axis. To approximate the UCSR, it is appropriate to use the power function of cumulative snowfall. The power function takes the form of Equation (5).

4. RELATIONSHIP BETWEEN UCSR AND CUMULATIVE SNOWFALL DETERMINED BY USING PREVIOUS SNOW REMOVAL DATA

The relationship between UCSR and cumulative snowfall is examined here for prefecturally managed national highways and prefectural roads that are in the areas subject to *The SCA Law*.

Approximation of that relationship on a prefecture-by-prefecture basis is done by using a UCSR-line model for each prefecture's previous snow removal cost and cumulative snowfall, so as to determine a correlation coefficient by regression analysis.

The details of the data that have been collected by prefecture and are used in the approximation follow: 1) annual cumulative snowfall for ten FY years from FY1995 to FY 2004, 2) annual snow removal costs from FY1995 to FY 2004 and 3) the length of the road with snow removal. The data for 2) and 3) are for those prefecturally managed national highways and prefectural roads whose snow removal costs are shared between the national government and the prefecture as prescribed by *The SCA Law*. The annual cumulative snowfall is the average of cumulative snowfall measured once everyday at several measurement sites within a prefecture. The length of road designated for snow removal by the law is set when the annual budgetary request is made.

4.1 Comparison of the Coefficient of Determination Among the Prefectures

Here we introduce how we can make inter-regional comparison of snow removal cost effectiveness by taking prefectures in the Hokuriku Region and Tohoku Region as examples. In Figure 4, UCSR correlates extremely closely with cumulative snowfall for Niigata, Toyama, and Ishikawa prefectures, whose roads are under the jurisdiction of the Hokuriku Regional Development Bureau, Ministry of Land, Infrastructure, and Transport (MLIT). The coefficient of determination is 0.88 (FIGURE 4).

An approximation line of the relationship was obtained for five of the six prefectures in the Tohoku Region, excluding Aomori Prefecture; the coefficient of determination for those five prefectures was low, 0.096 (FIGURE 5(1)). We assume that the UCSR differs depending on the climate and other regional characteristics, and we obtained one liner approximation for the prefectures on the Japan Sea side of the Tohoku Region and another for those on the Pacific side of that region. Under such a division, the correlation is higher, with a coefficient of determination of 0.39 for the Japan Sea side group and a coefficient of determination of 0.57 for the Pacific side group. This examination confirmed that areas with similar natural and local conditions have similar trends in the relationship between the UCSR and cumulative snowfall, and it is possible to group more than two prefectures for this examination (FIGURE 5(2)).

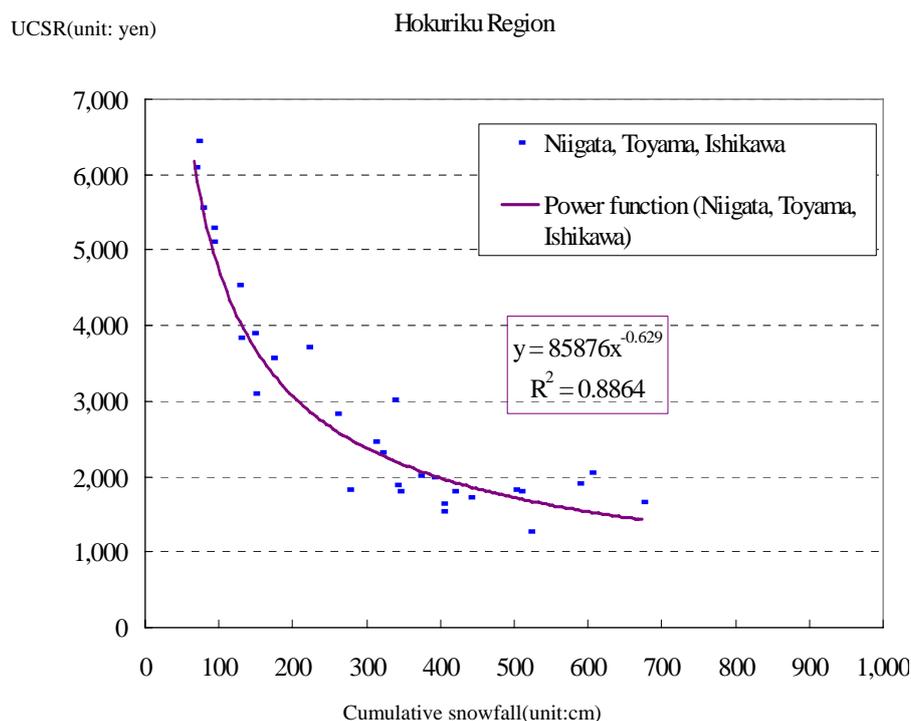


Figure 4 UCSR line for the Hokuriku Region (Niigata, Toyama, Ishikawa)

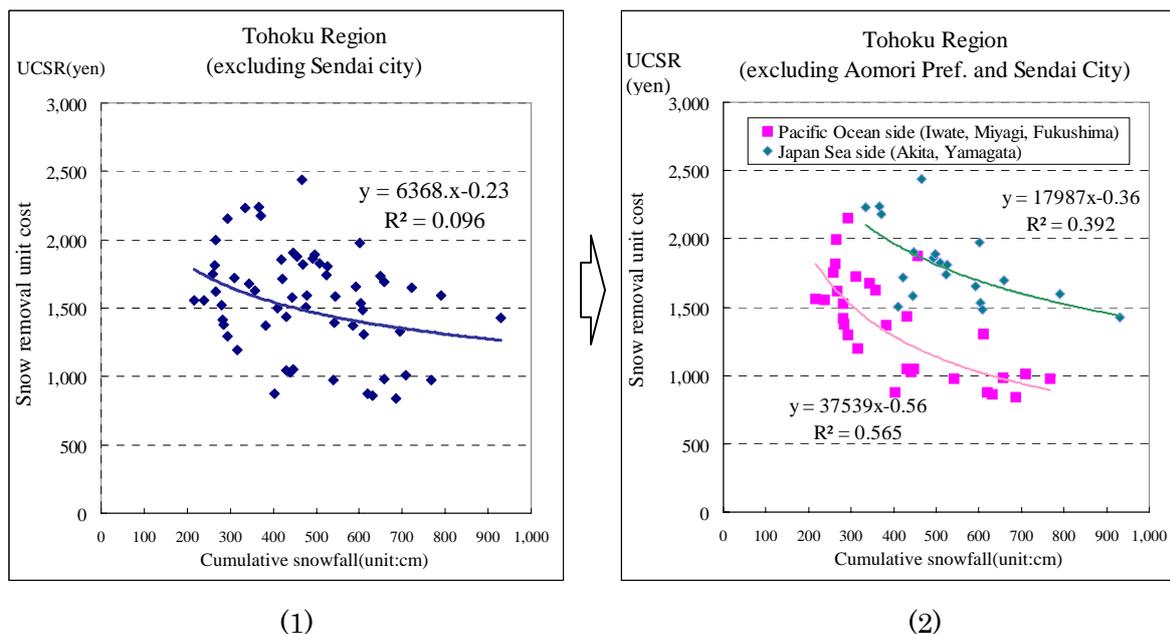


FIGURE 5 UCSR line for the Tohoku Region

4.2 Coefficients of Determination for Regions

A scatter plot of UCSR vs. cumulative snowfall for nationally managed national highways administered by the seven Regional Development Bureaus listed in FIGURE 6 reveals three groups. The first is roads administered by the Kanto Regional Development Bureau (Group A), for which the data points cluster around a higher region in the graph than the data points for other groups. The second is roads administered by the Chugoku Regional Development Bureau, for which the data points cluster in the lower region (Group B). The third is roads administered by the Hokkaido Regional Development Bureau and other regional bureaus excluding the Kanto and Chugoku Regional Development Bureaus, for which the data points distribute along a lined region (Group C) between the regions for Groups A and B (Figure 6).

FIGURE 7 (1) and (2) show a line correlating the UCSR and the cumulative snowfall for all the national highways administered by the national government, and that line for Group C, respectively. The coefficient of determination for the former is 0.25, and that for the latter is high: 0.77. In light of this, we assume that there are three UCSR lines. Group C can be explained by using one UCSR line. For Group A, whose line is the upper-rightmost line, the UCSR is high. For Group C the snow removal cost is low.

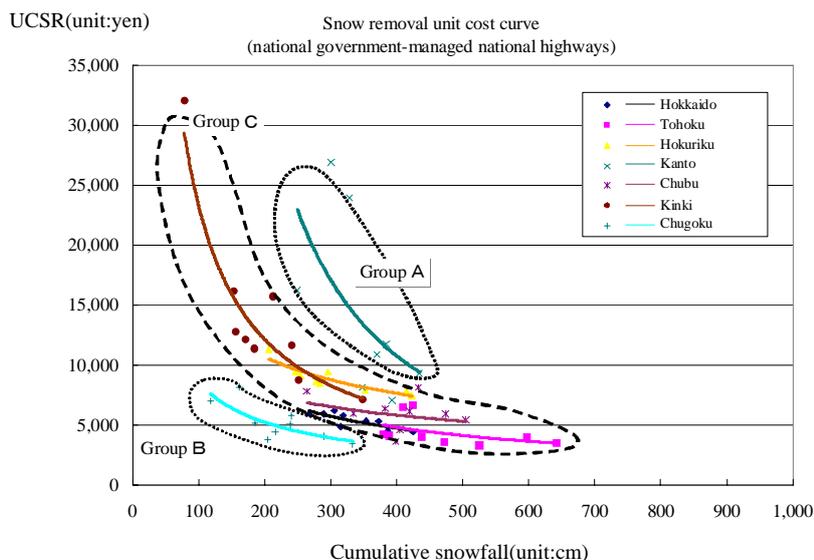


Figure 6 UCSR line for each region

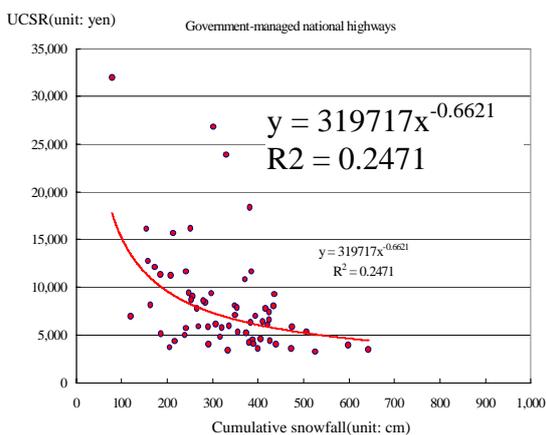


Figure 7 (1) UCSR line for all government-managed national highways

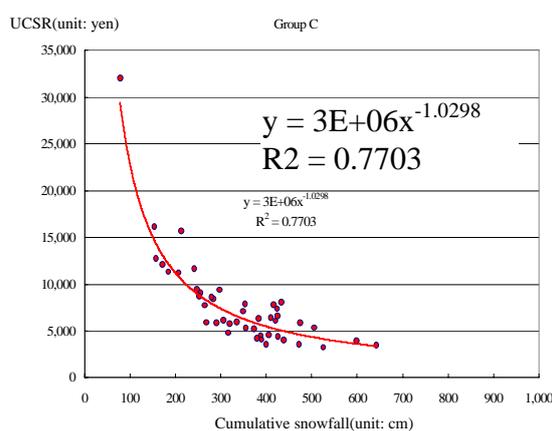


Figure 7 (2) UCSR line for Group C

Table 1. shows the coefficients of determination for national highways managed by the national government and those managed by prefectural governments.

It was found that the coefficients of determination for prefectures in the Chubu Region is low for national highways administered by the national government, and the coefficients of determination for Iwate, Gunma, and Okayama prefectures are particularly low for prefecturally managed national highways. It was found that the correlation coefficients tend to be high for areas on the Japan Sea side of the Tohoku and Hokuriku Regions, where the cumulative snowfall is large. For areas such as Chugoku, where the cumulative snowfall is quite small, and the Kanto and Tohoku areas on the Pacific coast, where cold but less snowy areas than the Japan Sea side areas account for a high proportion of the overall area, the coefficients of determination are relatively low (TABLE 1). These results verify the applicability of the UCSR-line model that assumes the relationship between cumulative snowfall and snow removal cost, where the larger the former is the latter is smaller.

Table 1 UCSR vs. cumulative snowfall: coefficients of determination for national highways managed by the national government and those managed by prefectures

| Region | Prefecture | Nationally managed national highways | Prefecturally managed national highways |
|-----------------|-----------------|---|---|
| | | Coefficient of determination | Coefficient of determination |
| Hokkaido | Hokkaido | 0.666 | 0.581 |
| Tohoku Region | Aomori Pref. | 0.264 | 0.175 |
| | Iwate Pref. | | 0.021 |
| | Miyagi Pref. | | 0.313 |
| | Akita Pref. | | 0.394 |
| | Yamagata Pref. | | 0.753 |
| | Fukushima Pref. | | 0.308 |
| Kanto Region | Tochigi Pref. | 0.315 | 0.196 |
| | Gumma Pref. | | 0.071 |
| | Nagano Pref. | | 0.479 |
| Hokuriku Region | Niigata Pref. | 0.907 | 0.393 |
| | Toyama Pref. | | 0.699 |
| | Ishikawa Pref. | | 0.892 |
| Chubu Region | Gifu Pref. | 0.095 | 0.249 |
| Kinki Region | Fukui Pref. | 0.853 | 0.235 |
| | Shiga Pref. | | 0.924 |
| | Kyoto Pref. | | 0.534 |
| | Hyogo Pref. | | 0.276 |
| Chugoku Region | Tottori Pref. | 0.585 | 0.812 |
| | Shimane Pref. | | 0.198 |
| | Okayama Pref. | | 0.013 |
| | Hiroshima Pref. | | 0.233 |
| | Yamaguchi Pref. | | 0.247 |

Detailed analyses are necessary toward understanding the reasons for the low correlation in these areas. One possible reason is that in Iwate Prefecture or Gunma Prefecture, areas that tend to have low temperatures and little snowfall account for a low proportion of the overall area, which results in high cost for anti-freezing agent application. For Okayama Prefecture, where snowfall is small, a possible reason for the low correlation coefficient is that fixed cost accounts for a large share of the total snow removal cost.

5. COST COMPARISON USING THE UCSR LINE

5.1 Cost Efficiency of Snow Removal for Each Prefecture

The UCSR line is an empirical formula obtained from snow removal records. By using this line, it is possible to estimate the UCSR that corresponds to a particular cumulative snowfall.

It is possible for a prefecture to use the UCSR line to evaluate the cost efficiency of its snow removal for any given year, by comparing the estimated snow removal cost and the actual cost expended.

5.2 Applicability of the UCSR Line Obtained From the Snow Removal Data for Years Including an Extremely Snowy Year and a Less Snowy Year

Through 2005-2006 winter (FY2005), extremely heavy snowfall was seen all over Japan including the Hokuriku Region. The Meteorological Agency designated it “the Heavy Snowfall of 2006” for the first time in 43 years. Meanwhile, the annual snowfall in the Hokuriku Region for 2006-2007 winter (FY2006) was quite light. We will take up the Hokuriku Region to verify the applicability of the UCSR-line model, examining whether a UCSR line plotted by using the snow removal data for years with unusual weather in winter would be useful. Figure 8 shows two UCSR lines for the Hokuriku Region: one line plotted by using snow removal data from FY 1995 to 2004 and another line plotted by using the data from FY 1994 to 2007 including an extremely snowy year (FY 2005) and a unusually less snowy year (FY 2006). Figure 8 shows the coefficients of determination for the two lines.

UCSR (unit: yen)

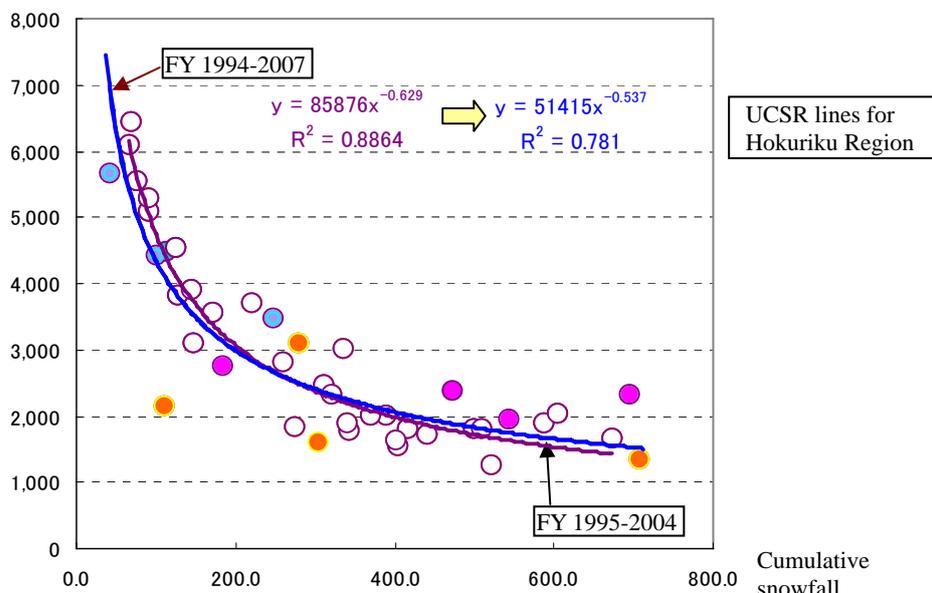


Figure 8 Comparison of UCSR lines, one of which is obtained from the data of years (FY 1994-2007) including an extremely snowy year and a less snowy year

Table 2 Comparison of UCSR for Niigata Prefecture (unit for UCSR: yen)

| Year | 2005 | 2006 | 2007 |
|--|-------|-------|-------|
| a) Actual UCSR | 2,327 | 2,760 | 2,390 |
| b) UCSR estimated by the UCSR-line model | 1,531 | 3,123 | 1,882 |
| Disparity between a) and b) | 796 | -363 | 508 |

As shown in Figure 8, the coefficient of determination (R^2) of the UCSR line obtained from the snow removal data for the years (FY 1994-2007) including an extremely snowy year and a less snowy year is relatively high 0.78, compared with another line plotted on the basis of the data of the years (FY 1995-2004) that do not include those with such extreme weather in

winter. The scatter plots in Figure 9 identify that snow removal costs for all the prefectures are high in FY 2005. The probable cause for the high snow removal costs in FY 2005 is that higher costs of snow hauling due to low snow thaw resulting from the longer period of time with low temperatures than other years.

Next, we examine the cost efficiency of snow removal costs for different years for Niigata Prefecture by comparing the snow removal cost estimated by the UCSR line and the actual cost expended. The UCSR for FY 2005 is 2,327 yen (Table 2), which is almost the same as that 2,390 yen for FY 2007. However, comparing the actual UCSR with that estimated by the UCSR line in Figure 9, the UCSR for 2007 can be evaluated more cost efficient than that for FY 2005 because the disparity between the actual UCSR and that estimated by the UCSR line (Figure 9) is smaller for FY 2007 because of less cumulative snowfall of the year than that in FY 2005. The actual UCSR for FY 2006, 2,760 yen (Table 2) is higher than that for FY 2005 and 2007, however it is lower than the UCSR estimated by the UCSR line (Figure 9), which means the snow removal work in FY 2006 was supposed to be conducted in the most cost efficient manner for the prefecture in these three years. Figure 9 also shows that the snow removal cost for Toyama Prefecture is the lowest every year, compared with the cost for other prefectures.

As explained above, the UCSR line offers standards to evaluate the efficiency of snow removal costs for different regions. The standards are useful to evaluate appropriateness of snow removal budgeting as well as to identify cost-efficient snow removal work so as to finally realize snow removal cost reduction. In the case of Niigata Prefecture, snow removal work status for FY 2006 should be studied to seek the most cost efficient snow removal because though the prefecture's actual UCSR for FY 2006 is the highest among those for the three fiscal years, it is lower than the estimated UCSR by the UCSR line and the disparity from the estimated UCSR is the smallest among those for the three years (Figure 9).

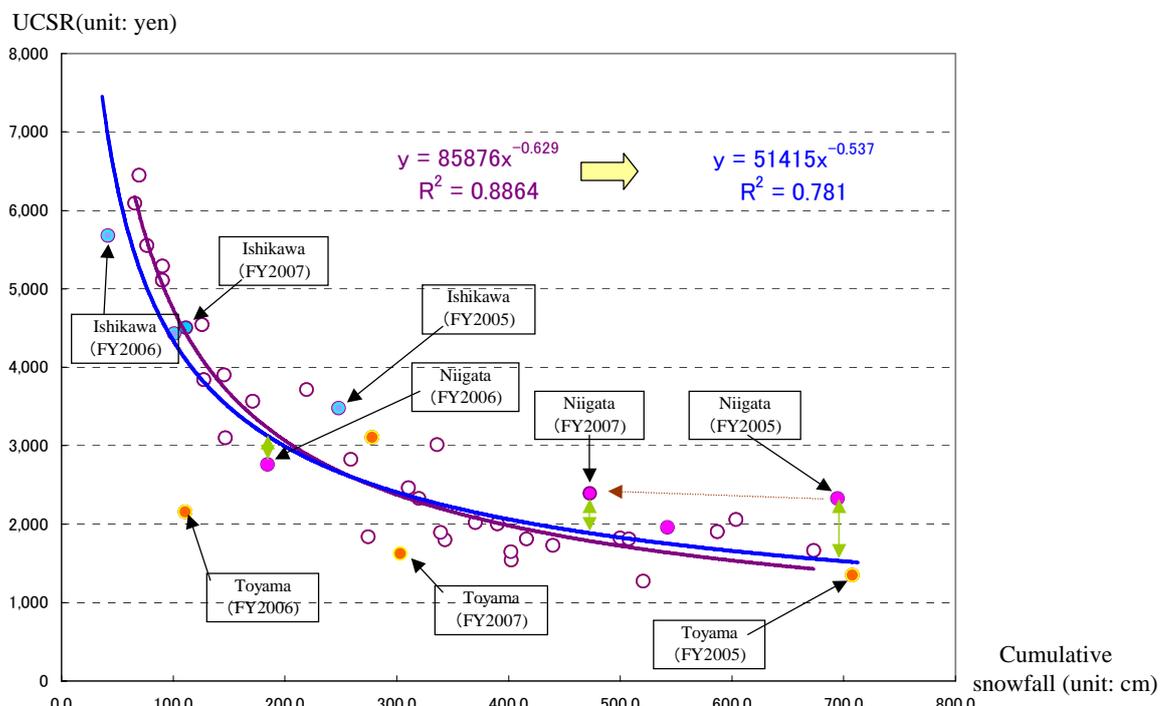


Figure 9 Comparison of the actual UCSR and estimated UCSR by the UCSR-line model for prefectures in the Hokuriku Region (FY 2005~2007)

8. SUMMARY

8.1 Important Points of This Study

- a. A model was proposed for analyzing the relationship between the snow removal cost and cumulative snowfall using the UCSR line.
- b. Snow removal cost comparison using the UCSR line was proposed.
- c. The applicability of the model was verified by comparing the snow removal costs estimated by the UCSR-line model with the actual snow removal costs expended.
- d. The applicability of the UCSR line obtained from the snow removal data for years that include those with unusual weather in winter was examined by using actual data.
- e. Issues regarding budget allocation using the UCSR line were successfully addressed, which has enabled the method to be applied to budgeting by the national government.

8.2 Items to be Improved

The following list shows the items that shall be examined for improvement of the accuracy of snow removal cost estimation and further reductions in snow removal cost.

- a. Comparison between prefectural and national government data.
- b. Analysis of reasons for the low correlation between the UCSR and cumulative snowfall of some prefectures, which will enable better comparison with nearby prefectures.
- c. Examination of the correlation between cumulative snowfall and UCSR after subtracting snowfalls smaller than the standard for snow removal deployment (5 cm (0.4 in.)/day).
- d. Examination of the correlation between the number of frost days and the amount of anti-freezing agent applied.
- e. Derivation of a correction term for improved snow removal budget allocation that takes into account the approximation formula and the degree of dispersion of each data set.
- f. Examination of the influence of unit labor cost on snow removal on UCSR.
- g. Examination using “approximation zones” that take data dispersion into account.

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