A COST BENEFIT ANALYSIS APPROACH BASED ON LAND VALUE FOR SNOW CONTROL ON URBANIZED AREA IN JAPAN

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1. Abstract

In these days, large scale snow transporting systems, such as snow removing ditch networks and/or new snow-melting technologies, are planning to introduce to snowy regions in Japan. They need considerably higher cost to pay comparing with conventional systems: snow plowing, sprinkle melting and truck transportation. When making decision of measures for snow control, though cost benefit analysis is one of the important approach, there was no way to estimate the benefit of snow removal from urbanized area of snowy regions.

In this paper we propose a simple cost benefit analysis approach based on land value for snow control on urbanized area. The principal factor of snow damage is the spatial occupation by snowcover and/or snow bank formed by snow displacement operation. According to an assumption that the benefit brought by a new snow removing system corresponds to the land rent fee of that place multiplied by the area cleared by the system, benefit cost ratio, B/C, is easily calculated from declared data, such as land value, planning area and cost for the system.

Case studies of conventional systems, snow plowing, sprinkle melting and snow removing ditch networks, were carried out in Nagaoka City and Tokamachi City, Niigata Prefecture. Benefit cost ratios of the conventional systems are more than 10 and are strongly affected by the amount of snowfall in the winter and the land value of the place. Validity of these results is confirmed with the results of some other cost benefit analysis for snow plowing operation. While the benefit cost ratio of the snow removing ditch networks had installed in Tokamachi City is approximately one, hence it is concluded that the system is economically efficient.

2. Introduction

Since the early 1960's, introduction of snow plowing vehicles and development of sprinkle snow melting technique have brought to snowy region in Japan an enhancement of economical activities as well as in non-snowy region. In the mid of 1970's, new snow-removal technologies, such as hydraulic/pneumatic snow transportation system and road heating system, had energetically developed, however these still had not be full-blown prevailing because of their relatively high cost.

After the latest heavy-snow fall winter, 1986 winter, we have not experienced such severe heavy-snowfall for about 15 years. In the last decade, people have become to be desired higher level sustenance of urban activities even in winter term, and more comfortable urbanity. Therefore snow control cost is rapidly increasing because of expansion of snow removal area and introduction of large-scale snow removal systems.

When a local government makes decision about snow control policy, cost benefit analysis is very important to explain to citizen as taxpayer and to build a consensus on service level with citizen as recipient of the benefits. But such benefit evaluation has not been conducted.

Umemura et. al. (1991) had defined and calculated the amount of snow damage in an urban area with heavy snowfall, and this makes it possible to evaluate the benefits of a snow control system s. The present paper has proposed the evaluation method and applied it to the representative snow control systems: sprinkle melting, snow plowing, and small-scale snow removing ditch, and large-scale snow removing ditch network. The annual costs and benefits of these systems are calculated and its economic effectiveness is evaluated from cost- benefit ratios.

3. Method of Cost –Benefit Analysis

To evaluate economic effectiveness of a snow control system in a given place, snow damage and snow control costs before and after the introduction of the system are compared. Suppose that the snow control cost is C_1 and the amount of snow damage is D_1 before the introduction, and similarly C_2 and D_2 after the introduction, as shown in Figure 1. C_2 includes the cost of the snow control system, C, and ΔC_1 in Figure 1 indicates the reduction of C_1 by introducing the snow control system.

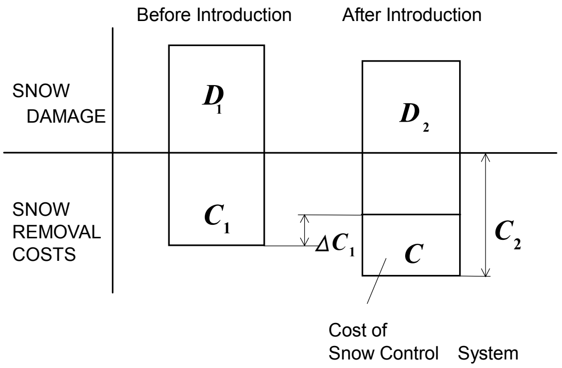


Figure 1. Economic Effects of Snow Control System

The economic effectiveness of the ditch can be judged by comparing C_1+D_1 and C_2+D_2. Namely, the snow removing ditch is considered to be economically effective if

$$C_1 + D_1 > C_2 + D_2 \tag{1}$$

Since C_2 equals C_1- ΔC_1+C as shown Figure 1, Formula (1) is written as

$$(D_1 - D_2) + \Delta C_1 > C \tag{2}$$

Let the left side of Formula (2) be defined as the benefit of the snow removing ditch, B, which consists of the benefit $B1 \equiv D_1 - D_2$ and benefit $B_2 \equiv \Delta C_1$. Both B and C are evaluated in annual amounts and the degree of economic effectiveness is expressed by benefit-cost ratio B/C.

$$B/C \equiv (B1 + B2)/C > 1 \tag{3}$$

3.1 Benefit Evaluation

(1) Snow Damage Reduction Benefit *B*1

By means of the method proposed by Umemura (1991) and modified by Kamimura and Umemura (1993), the annual amount of snow damage, D, in a given place is expressed as

$$D = \overline{k}(rL + F)A \tag{4}$$

where

$\overline{k}$ = annual mean seasonal drop factor in utilization,
r = annual rate of interest,
L = land value of a unit area,
F = annual expense of a unit area for facilities on the place, and
A = area of the place (m^2).

$\overline{k}$ means $\Sigma k/365$ where k is the daily seasonal drop factor in utilization and Σk is the annual sum of k. Here k is 0 if the place can be completely used in a snowy season as well as a non-snowy season and k is 1 if the place can not be used at all in a snowy season because of snowcover. And k takes between 0 and 1 if the place is partly used in a snowy season. Thus $\bar{k}$ is given as

$$\bar{k} = \frac{R \cdot N}{365} \tag{5}$$

where

R = average value of "snow covered area/given place area" for N days, and

N = number of snowcover days given by local meteorological observatory.

Since the snow damage D_1 and D_2 in Figure 1 are expressed as $\bar{k}_1(rL+F)A$ and $\bar{k}_2(rL+F)A$ from Equation (3), the benefit $B1$ can be expressed as

$$\begin{aligned} B1 &= D_1 - D_2 = (\bar{k}_1 - \bar{k}_2)(rL+F)A \\ &= \frac{R_1N_1 - R_2N_2}{365}(rL+F)A \end{aligned} \tag{6}$$

(2) Cost Reduction Benefit *B*2

The benefit $B2$ is mainly brought by the decrease of the cost paid for conventional system. As an example, when all/part of snow disposal works by trucks are replaced by snow removing ditch, $B2$ is evaluated as

$$B2 = C_T \cdot W \cdot A' \tag{7}$$

where

C_T = cost of transportation work by trucks for 1 ton of transported snow,

W = annual amount of transported snow in a unit area of A', and

A' = snow covered area where snow transportation by trucks to be replaced by snow removing ditch.

3.2 Snow Disposal Demand from Residential District

(1) Target Area

Only residents of houses near snow removing ditches, in general, use the ditches to remove the snow on the roads, sidewalks and housing sites around them. Therefore, the snow removal area of the snow removing ditch system, where the benefits of the system are brought, can be defined as above three parts: Roads, Sidewalks and Housing Sites. In the case of the ditches being constructed on both sides of the road, the extent from the center of the road to the back of the housing site with a depth of 20m is taken in the snow removal area as shown A in Figure 2. Furthermore, in the case of the ditches being constructed on one side of the road, the extent between two back lines of both housing sites with each depth of 20m is taken in the area as shown B in Figure 2.

The benefits of the system depend on the above part and its means of snow removal. Therefore, in the snow removal

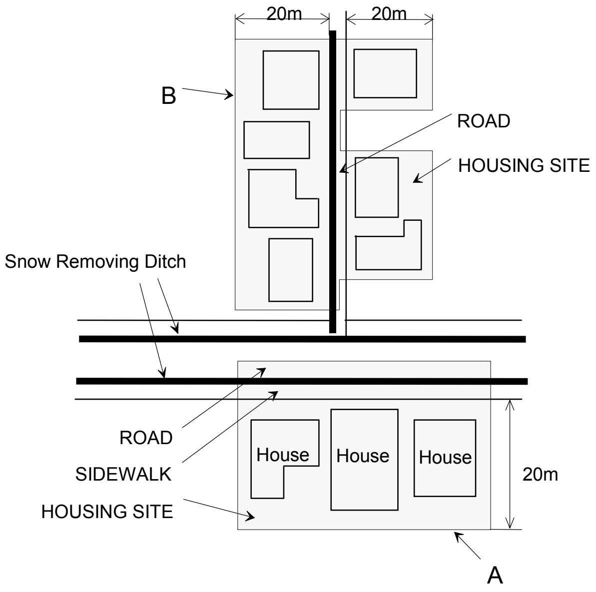
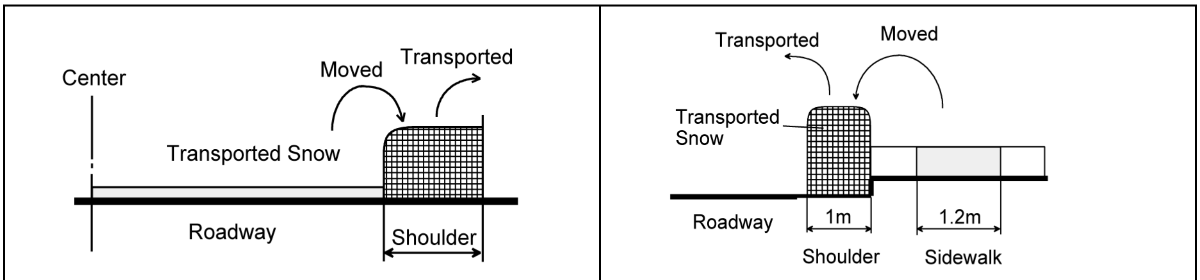
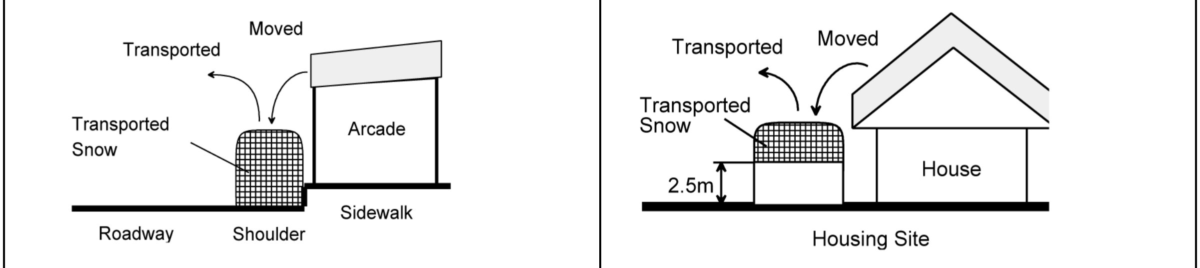


Figure 2. Snow Removal Areas



(a) Road model cleared by plowing

(b) Sidewalk model cleared by plowing



(c) Sidewalk model with arcades

(d) Housing site model with snow disposal demand

Figure 3. Snow Distribution and Transportation Models

area, the benefits are evaluated on the following six items: Roads cleared by snow plowing, Roads with snow melting pipes, Sidewalks cleared by snow plowing, Sidewalks with arcades, Housing Sites with snow disposal demand (e.g. where houses require roof snow removal and the spaces around the houses are not enough) and Housing Sites without snow disposal demand (e.g. where houses have the equipment for melting the roof snow). Equation (6) and Equation (7) are applied to each item to evaluate the benefit $B1$ and $B2$ of the system, respectively.

(2) Snow Distribution and Transportation Models

W in Equation (7) on each item is calculated through computer simulation (Kamimura and Umemura, 1992) using each model shown in Figure 3. These models simulate the distribution of removed snow using the daily-observed snowcover data in the given place. In these models, W is calculated as the sum of the daily amount of snow transported, which cannot be displaced and then transported.

Figure 3(a) is the model of Roads cleared by snow plowing. When the depth of snow on the roadway reaches 10cm (density of 100kg/m^3), it is moved to the shoulder by a tractor with blade plow. When this snow depth reaches 1.1m (density of 300kg/m^3), the limit to displace snow by the tractor with blade plow, the snow on the shoulder is loaded by a snow rotary plow onto a dump truck and transported to other places. The shoulder width takes 30% of the road width

Figure 3(b) is the model of Sidewalks cleared by snow plowing. When the depth of snowcover on the sidewalk reaches 15cm (density of 100kg/m^3), the snow on the 1.2m wide in the sidewalk is moved to the shoulder by a small rotary plow. When the depth of snow on the shoulder reaches 1.1m, it is transported in the same manner as the model of Roads cleared by snow plowing.

Figure 3(c) is the model of Sidewalks with arcades. When the roof snow depth on the arcade reaches 1m (density of 200kg/m^3), it is manually thrown down to the shoulder and transported immediately by a rotary plow and dump truck.

Figure 3(d) is the model of Housing Sites with snow disposal demand. When the roof snow depth on the house reaches 1m (density of 200kg/m^3), it is manually thrown down to the ground around the house. When this snow depth exceeds 2.5m (density of 350kg/m^3), the exceeded part of the snow is transported so as not to touch the eaves of the house.

4. Case Studies

4.1 Snow Plowing and Sprinkle Melting System in Nagaoka City

The method mentioned above is applied to the most popular two systems, snow plowing system and sprinkle snow melting system in the Central Commercial District of Nagaoka City. The area of approximately 0.8 km^2 has 16.1 km road length including 13.6 km sprinkle melting lane. Representative winters, such as snow abundant winter, average snow winter and snow scarcity winter have chosen to evaluate these snow control systems. Seeing statistical average winter data in Nagaoka City, annual maximum snow depth, HC, is 1.3 m, cumulative daily snowfall depth, TF, is 5.4 m and snow naturally covers for 92 days (N) in a winter.

(1) Evaluation of Benefit *B*1

For the evaluation of these two systems, we just need to consider only benefit $B1$. Benefit can calculate with comparing current situation, i.e. current snow-cleared area and period with current system conditions, with virtual situation that the system completely does not work, i.e. no area cleared and snow covers whole winter days in every road.

Cleared area ratio is given according to the characteristics of the system; for example, whole of the road would be cleared with sprinkle melting, 80 percent of the road would be cleared by snow displacement by snow plowing machines.

Interest rate r in Equation (6) of 0.06 is given as the typical rate of interest used in the previous study (1), and Land value L is taken from the street values in the snow removal area. Average value of L in the snow removal area is 570,000 yen/m^2. F in Equation (6) is 2,340 yen/m^2 calculated from the recent records of the costs for road construction and maintenance in Nagaoka City.

(2) Evaluation of Costs *C*

The annual cost of the system, C, consists of construction costs, maintenance costs and running costs. Construction cost and maintenance costs is given by recent record for each system. Running cost is given by proportional relationship of the records with snow data, such as TF or N.

4.2 Snow Removing Ditch Systems in Tokamachi City and Nagaoka City

The method mentioned above is also applied to two snow removing ditch systems: small-scale system in Nagaoka City (Nagaoka SRD System) and large-scale system in Tokamachi City (Tokamachi SRD System). The Nagaoka SRD System is constructed in the residential district of 0.25km^2 area. While the Tokamachi SRD System is constructed in the urban area of 1.9km^2 where 15,000 residents live. The City has a heavy amount of snowfall; the average annual maximum snow

Table 1. Specifications of Two Snow Removing Ditch Systems

	Tokamachi SRD System		Nagaoka SRD System	
Total ditch length	43.2	km	1.35	km
Pipeline length	6.76	km	N/A	km
Ditch width	0.5	m	0.5	m
Ditch depth	over 0.5	m	over 0.5	m
Water flow depth	0.2	m	0.25	m
Water resource from	2.1	m^3/sec	0.117	m^3/sec

depth is 2.5m and the highest depth on record is 4.25m.

Table 1 shows the specifications of two snow removing ditch systems. The Tokamachi System consists of open ditches, pipelines and pumps for water supply. Water of 2.1m^3/sec is pumped up from two rivers for 11 hours per day, and distributed to each ditch route according to the timetable.

(1) Evaluation of Benefit *B*1

To show a procedure to evaluate benefit $B1$, Table 2 shows the value of R_1, R_2 and A in Equation (6) for each item for Tokamachi SRD System. In Roads cleared by snow plowing, R_1 is estimated to be 0.16 taking into consideration that the road shoulder is partly covered with snow, about 16% of the road area. And R_2 is 0 on the assumption that all the snow on the shoulder is thrown into the ditches after the introduction of the system. In Roads with snow melting pipes and Sidewalks with arcades, both R_1 and R_2 are 0 because there are almost no snowcover. In Sidewalks cleared by snow plowing, R_1 is estimated to be 0.39 taking into consideration that about 39% of the sidewalk area is covered with snow, and R_2 is 0 on the assumption that all the remaining snow on the sidewalk is thrown into the ditches after the introduction. In Housing sites, R_1 is 0.34 and R_2 is 0.28, which are the result of the questionnaire administered to the residents of Tokamachi City. r and L in Equation (6) are given by same manner mentioned above. F in Equation (6) is 2,460 yen/m^2 in Tokamachi City. On the other hand, F on Housing Sites are negligible.

Table 2. Values for Benefits Evaluation For Tokamachi System

Item in Snow Removal Area	R_1	R_2	A (m^2)	A' (m^2)
Roads by snow plowing	0.16	0	72,980	21,890
Roads with snow melting pipes	0	0	25,930	0
Sidewalks by snow plowing	0.39	0	6,700	3,590
Sidewalks with arcades	0	0	6,580	6,580
Housing Sites with snow disposal demand	0.34	0.28	400,990	400,990
Housing Sites without snow disposal demand	0.34	0.28	139,360	0

(2) Evaluation of Benefit *B*2

C_T in Equation (7) is 1,063 yen/ton which is calculated from the snow removal records in Tokamachi City where snow rotary plows (power of 300PS) and dump trucks (capacity of 11ton) have been utilized for snow disposal.

A' for each item is shown in Table 2. On Roads cleared by snow plowing, A' is the area of the shoulder, which is 30% of A. On Roads with snow melting pipes, A' is 0 because the snow disposal works are not needed. In Sidewalks cleared by snow plowing, A' is the area for snow removal by small rotary plows, 1.2 m wide × 2,992 m long. In Sidewalks with arcades, A' is the roof area of arcades, the same as A. In Housing sites with snow disposal demand, A' equals A, and in Housing Sites without snow disposal demand, A' equals 0.

(3) Evaluation of Costs *C*

The construction cost is 243 million yen/year, which is determined by the evaluated cost of the total construction, 4,860 million yen, divided by an assumed lifetime, 20 years. The maintenance cost is 5 million yen/year obtained from the recent records in Tokamachi City. The running cost, annual electricity charges for the pumps, is evaluated at $5+0.12N$ million yen/year, assuming that the pumps are operated 11 hours per day for snowcover days N. As the sum of those costs, C is calculated as

$$C = 253 + 0.12N \qquad \text{(million yen)} \tag{7}$$

These cost estimation procedure also applied to the Nagaoka SRD System.

5. Analysis Result

The analysis results of the benefits, costs and cost-benefit ratios, *B*/*C*, for these snow control system summarized in Table 3. The snow plowing system has relatively high *B*/*C* of 7.6 and 10.7 for snow abundant winter and average snow winter respectively. Comparing the results with previous work, Igarashi (1971) shows the *B*/*C* equals to 5.7 for snow plowing in Sapporo, Japan, and Sakai et. al. (1993) showed B/C of 5.7 in average using total snow-removal budget in whole area of Niigata Pref., Japan. This comparison shows the validity of the results. In addition, the B/C value strongly affected the Land value of the place, therefore B/C values vary ranging 3.1 to 19.7 for separated street block having 260 to 1400 thousand yen/m^2. It can be seen that sprinkle melting system also has almost same economical effectiveness in Table 3.

The results of economic analysis using statistical snow data for small-scale SRD system in Nagaoka shows that its *B*/*C* value is around one, i.e. its economic effectiveness depends on the amount of snowfall. Using the snowfall and snow depth date for 20 years from 1975 through 1994, the benefits, costs and benefit-cost ratios of the snow removing ditch system in Tokamachi City are calculated as shown in Table 3. The total benefit divided by the total cost for the 20 years is 0.85, proving that this system is not economically effective. However, the economic effectiveness depends on the amount of snowfall. For example, the benefit-cost ratios for the first decade (1975-1984, average annual maximum snow depth of 2.77m) and second decade (1985-1994, 1.94m) are 1.08 and 0.62, respectively.

Figure 4 shows the relation between both the annual benefits and costs and the annual maximum snow depths for the 20 years. The benefits increase in an accelerated manner as the maximum snow depths increase, but the costs are almost constant. Consequently, the benefit-cost ratios are expressed by the same plot as the benefits according to the scale of the right vertical axis. From this result, it follows that when the annual maximum snow depth is greater than about 3m, the system has an annual benefit-cost ratio of more than 1, proving that the system is economically effective.

Figure 5 shows the benefit *B*1 and *B*2 on Roads, Sidewalks and Housing Site in representative

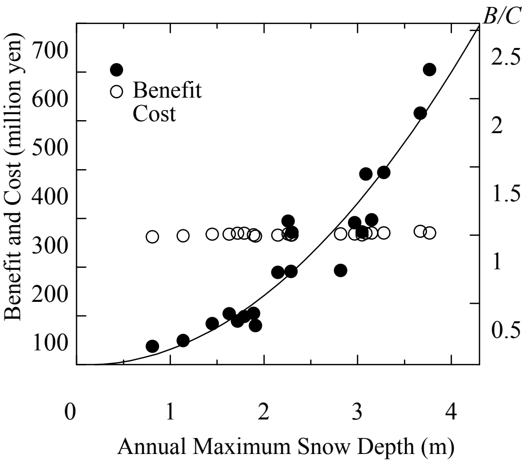


Figure 4. Benefit and Cost of the Tokamachi System.

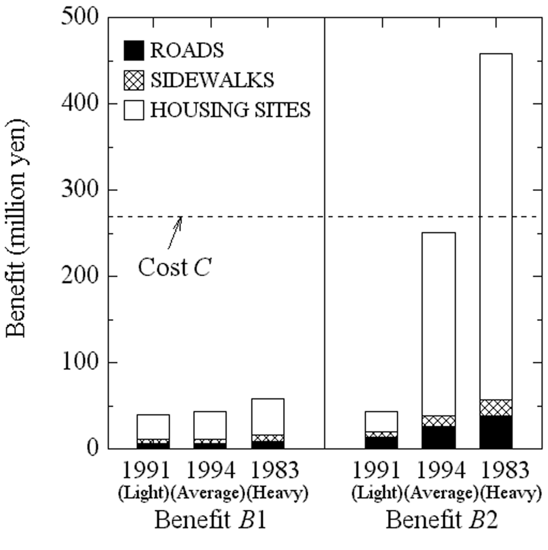


Figure 5. Benefit *B1* and *B2* on Roads , Sidewalk and Housing sites in representative years

years of light (1991), average (1994) and heavy snowfall (1983). It indicates that $B2$ is more than $B1$ and the major factor of the benefits is Housing Sites. $B2$ on Housing Sites increases considerably with increasing amount of snowfall. This is because the amount of transported snow by trucks which is altered by the system increases dramatically as the frequency of roof snow removal increases. This characteristic of $B2$ appears to determine the economic effectiveness of the system.

Table 3. Results of Cost-Benefit Analysis

	Snow Data		Results of Calculation			
Year	Maximum Snow Depth (m)	Snowcover Days (days)	Benefit $B1$ (million yen)	Benefit $B2$ (million yen)	Cost C (million yen)	B/C
Sprinkle Melting System in Central Commercial District of Nagaoka City						
B (’86)	1.26	92	1036	N/A	95.0	10.9
C (’85)	2.25	130	1567	N/A	97.6	16.1
Snow Plowing in Central Commercial District of Nagaoka City						
B (‘86)	1.26	92	683	N/A	64.0	10.7
C (‘85)	2.25	130	1068	N/A	141.0	7.6
Snow Removing Ditch System in Nagaoka City (Small-scale)						
A*1	0.60	71	6.27	0	8.34	0.75
B*2	1.26	92	8.13	1.15	8.36	1.11
C*1	2.31	127	11.24	3.44	8.38	1.79
Snow Removing Ditch System in Tokamachi City (Large-scale)						
A (‘91)	1.45	113	40	44	267	0.31
B (’94)	2.26	123	43	251	268	1.10
C (’83)	3.67	166	58	458	273	1.89

A: Year of snow scarcity, B: Year of average snow, C: Year of snow abundant.
*1: 10-year return period, *2: 10-year return period.

7. Conclusion

In this paper we propose a simple cost benefit analysis approach based on land value for snow control on urbanized area. The principal factor of snow damage is the spatial occupation by snowcover and/or snow bank formed by snow displacement operation. According to an assumption that the benefit brought by a new snow removing system corresponds to the land rent fee of that place multiplied by the area cleared by the system, benefit cost ratio, B/C, is easily calculated from declared data, such as land value, planning area and cost for the system.

Case studies of conventional systems, snow plowing, sprinkle melting and snow removing ditch networks, were carried out in Nagaoka City and Tokamachi City, Niigata Prefecture. Benefit cost ratios of the conventional systems are more than 10 and are strongly affected by the amount of snowfall in the winter and the land value of the place. Validity of these results is confirmed with the results of some other cost benefit analysis for snow plowing operation. While the benefit cost ratio of the snow removing ditch networks had installed in Tokamachi City is approximately one, hence it is concluded that the system is economically efficient.

This method is applicable to other places where a snow control system is planned to be constructed, and it will contribute to select the measures against snow damage there.

Acknowledgments
The authors would like to thank Nagaoka City Office and Tokamachi City Office for supplying much of the data used here and useful information about snow removal in that city.

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