Cost-Benefit Analysis of Snow-Removing Channels in an Urban Area with Heavy Snowfall

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In an urban area with heavy snowfall, such as the northwest coast of Japan bordering the Japan Sea, snow often becomes a serious obstacle. Therefore, advanced means of snow removal, such as a snow-removing channel, are required. The snow-removing channel, an open channel constructed on the shoulder of a road to provide water flow, can remove a large amount of snow quickly. However, because of the high construction costs, a benefit-cost analysis of the snow-removing channel is conducted to help determine whether a channel should be constructed. A method for estimating benefits of the snow-removing channel is proposed. The benefits are considered to consist of reduction of snow damage and snow removal costs. The reduction of snow damage costs is calculated from land value of and expenses incurred for the closed area that would be opened through the introduction of the channel. The reduction of snow removal costs is calculated from the costs of snow removal equipment. The present method is applied to the snow-removing channel system in the central area of Tokamachi City, Japan, which is about 1.9 km^2 and has a population of 15,000. The average annual maximum snow depth is 2.5 m. The total length of the channel is 43.2 km and water at the rate of 2.1 m^3/sec is pumped up from rivers to remove snow. The calculated benefits of the snow-removing channel system vary, equaling 84, 294, 394, and 516 million yen a year according to the annual maximum snow depth of 1.45 m (1991), 2.26 m (1994), 3.28 m (1985), and 3.67 m (1983), respectively. In addition, the benefit-cost ratios are given as 0.31, 1.10, 1.46, and 1.89, respectively. It is concluded that this system is economically effective when the annual amount of snowfall is more than the average.

In an urban area with heavy snowfall, the development of modern automotive society and the resulting change in lifestyle have caused residents serious snow problems. Residents cannot maintain their urban life without snow removal, and advanced means of snow removal are required.

A snow-removing channel, an open channel with water flow that is usually constructed on the shoulder of a road, is one method of effective snow removal. Residents throw the snow that has fallen on roofs, in yards, and on roads into the channel to create more open space and to keep roads clear for transportation. However, the construction costs for the snow-removing channel are fairly high, making the decision to build difficult for the local government. The decision to construct could be made effectively if the economic benefits of the channel were known. As yet such an evaluation has not been conducted.

The amount of snow damage in an urban area with heavy snowfall was defined and calculated (*1*), which makes possible the evaluation of the benefits of a snow-removing channel. The present study applies the evaluation method to the urban area of Tokamachi City, Japan, where a system of snow-removing channels is being constructed. The annual benefits and costs of the system are calculated and the system's economic effectiveness is evaluated from benefit-cost ratios.

METHOD OF BENEFIT-COST ANALYSIS

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

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

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

Because C_2 equals $C_1 - \Delta C_1 + C$, as shown in Figure 1, Equation 1 is written as

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

Let the left side of Equation 2 be defined as the benefit of the snow-removing channel, B, which consists of the benefit $B_1 = D_1 - D_2$ and benefit $B_2 = \Delta C_1$. Both B and C are evaluated in annual amounts and the degree of economic effectiveness is expressed by benefit-cost ratio B/C.

Benefit B_1

By means of the method proposed by Umemura et al. (*1*), the annual amount of snow damage, D, in a given place is expressed as

$$D = \bar{k}\left(rL + F\right)A \tag{3}$$

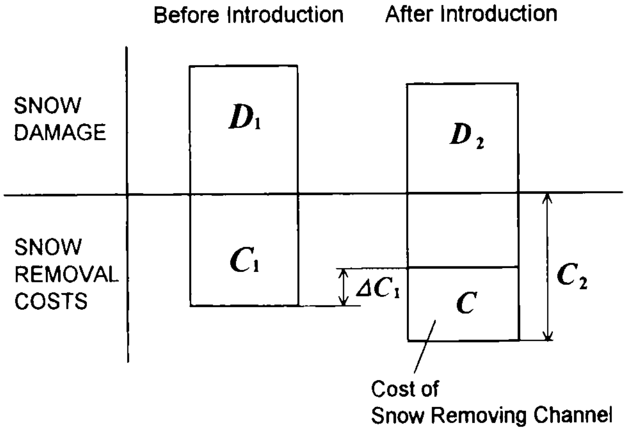

FIGURE 1 Economic effects of snow-removing channel.

where

$\bar{k}$ = 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 at the location, and
A = area of the location (m^2).

$\bar{k}$ means $\Sigma\, k/365$ where k is the daily seasonal drop factor in utilization and $\Sigma\, k$ is the annual sum of k. Here k is 0 if the location can be used completely in a snowy season as well as a nonsnowy season and k is 1 if the location cannot be used at all in a snowy season because of snow cover. k has a value between 0 and 1 if the place is partly used in a snowy season. Thus $\bar{k}$ is given as

$$\bar{k} = \frac{R \cdot N}{365} \tag{4}$$

where R is the average value of snow-covered area/given place area for N days, and N is the number of snow cover days given by the local meteorological observatory. Because 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 B_1 can be expressed as

$$\begin{aligned} B_1 &= D_1 - D_2 = \left(\bar{k}_1 - \bar{k}_2\right)\left(rL + F\right)A \\ &= \frac{\left(R_1 - R_2\right)N}{365}\left(rL + F\right)A \end{aligned} \tag{5}$$

Benefit B_2

Benefit B_2, the reduction of C_1 through introduction of the snow-removing channel, is mainly brought about by the decreased need for trucks for snow disposal. Thus let B_2 be evaluated as

$$B_2 = C_T \cdot W \cdot A \tag{6}$$

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 removal by trucks is to be replaced by the snow-removing channel.

SNOW-REMOVING CHANNEL SYSTEM IN TOKAMACHI CITY

This method is applied to the snow-removing channel system in Tokamachi City, which is being constructed in

TABLE 1 Specifications for Snow-Removing Channel System

Total channel length	43.2	km
Pipeline length	6.76	km
Channel width	0.5	m
Channel depth	over 0.5	m
Water flow depth	0.2	m
Water resource from rivers	2.1	m^3/sec

the urban area of 1.9 km^2 where 15,000 residents live. This city has a heavy amount of snowfall; the average annual maximum snow depth is 2.5 m and the greatest depth on record is 4.25 m.

Table 1 shows the specifications for the snow-removing channel system. The system consists of open channels, pipelines, and pumps for water supply. Water at the rate of 2.1 m^3/sec is pumped up from two rivers for 11 hr/day and distributed to each channel route according to the timetable.

Snow Removal Area

Only residents of houses near snow-removing channels, in general, use the channels to remove the snow from the roads, sidewalks, and housing sites around them. Therefore, the snow removal area that benefits from the snow-removing channel system can be divided into three parts: roads, sidewalks, and housing sites. In cases in which channels are constructed on both sides of the road, the area from the center of the road to the back of the housing site, which has a depth of 20 m, is the snow removal area, as shown at A in Figure 2. In cases in which channels are constructed on one side of the road, the area between the back lines of housing sites on either side of the channel, each with a depth of 20 m, is the snow removal area, as shown at B in Figure 2.

The benefits of the system depend on the snow removal area and its means of snow removal. Therefore, in the snow removal area, the benefits are evaluated on six items: (*a*) roads cleared by snow removal machines, (*b*) roads with snow-melting pipes, (*c*) sidewalks cleared by snow removal machines, (*d*) sidewalks with arcades, (*e*) housing sites with snow transportation demand (e.g., where houses require roof snow removal and the spaces around the houses are not large enough), and (*f*) housing sites without snow transportation demand (e.g., where houses have the equipment for melting the roof snow). Equations 5 and 6 are applied to each item to evaluate the benefits of B_1 and B_2, respectively.

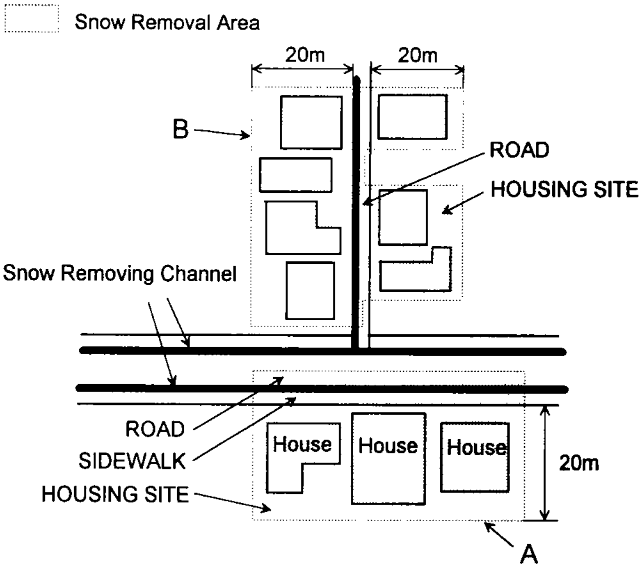

FIGURE 2 Snow removal area of channel system.

Evaluation of Benefit B_1

Table 2 shows the values of R_1, R_2, and A in Equation 5 for each item. In roads cleared by snow removal machines, R_1 is estimated to be 0.16, taking into consideration that the road shoulder, about 16 percent of the road area, is partly covered with snow. R_2 is 0 on the assumption that all the snow on the shoulder is thrown into the channels 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 is almost no snow cover. In sidewalks cleared by snow removal machines, R_1 is estimated to be 0.39, taking into consideration that about 39 percent 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 channels after their introduction. In housing sites, R_1 is 0.34 and R_2 is 0.28, reflecting the results of a questionnaire administered to the residents of Tokamachi City.

TABLE 2 Values for Benefits Evaluation

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

Moreover, r of 0.06 in Equation 5 is given as the typical rate of interest used in the previous study (*1*), and L for each item is taken from the street values in the snow removal area. F in Equation 5 is 2,460 yen/m^2 on roads and sidewalks, calculated from the recent records of the costs for road construction and maintenance in Tokamachi City. On the other hand, F on housing sites is negligible.

Evaluation of Benefit B_2

C_T in Equation 6 is 1,063 yen/ton, which is calculated from the snow removal records in Tokamachi City, where snow rotary plows and dump trucks (11-ton capacity) have been utilized for snow transportation.

A' for each item is shown in Table 2. On roads cleared by snow removal machines, A' is the area of the shoulder, which is 30 percent of A. On roads with snow-melting pipes, A' is 0 because the snow transportation works are not needed. In sidewalks cleared by snow removal machines, A' is the area 1.2 m wide and 2992 m long where snow is removed by small rotary plows. In sidewalks with arcades, A' is the roof area of arcades, which is equal to A. In housing sites with snow transportation demand, A' equals A, and in housing sites without snow transportation demand, A' equals 0.

W in Equation 6 on each item is calculated through computer simulation by using the models shown in Figures 3 through 6. These models simulate the distribution of removed snow by using the daily observed snow cover data in Tokamachi City. In these models, W is calculated as the sum of the daily amount of transported snow that cannot be displaced and then transported.

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

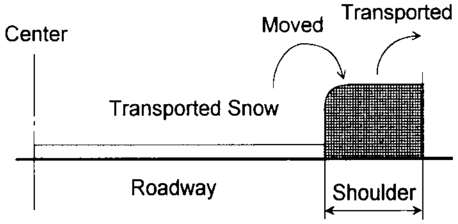

FIGURE 3 Model of roads cleared by snow removal machines.

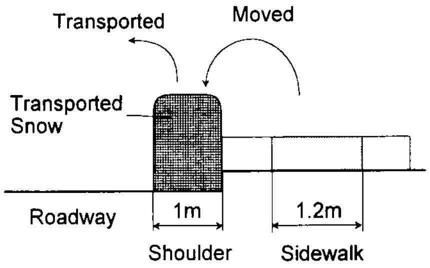

FIGURE 4 Model of sidewalks cleared by snow removal machines.

Figure 4 is the model of sidewalks cleared by snow removal machines. When the depth of snow cover on the sidewalk reaches 15 cm (density of 100 kg/m^3), the snow on the 1.2 m width in the sidewalk is moved to the shoulder by a small rotary plow. When the depth of snow on the shoulder reaches 1.1 m, it is transported in the same manner as in the model of roads cleared by snow removal machines.

Figure 5 is the model of sidewalks with arcades. When the roof snow depth on the arcade reaches 1 m (density of 200 kg/m^3), it is manually thrown down to the shoulder and transported immediately by a rotary plow and dump truck.

Figure 6 is the model of housing sites with snow transportation demand. When the roof snow depth on the house reaches 1 m (density of 200 kg/m^3), it is manually thrown down to the ground around the house. When this snow depth exceeds 2.5 m (density of 350 kg/m^3), the excess is transported so that it does not touch the eaves of the house.

COSTS AND ANALYSIS

The annual cost of the system, C, consists of construction costs, maintenance costs, and running costs. The construction cost is 243 million yen a year, which is determined by the evaluated cost of the total construction, 4,860 million yen, divided by an assumed life span of 20 years. The maintenance cost is 5 million yen a year, obtained from the recent records in Tokamachi City. The running cost, annual electricity charges for the pumps, is

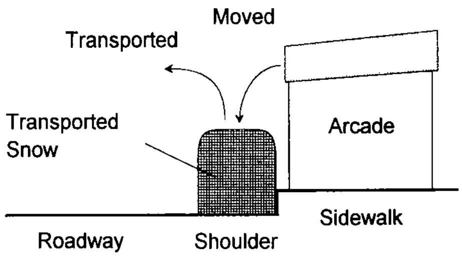

FIGURE 5 Model of sidewalks with arcades.

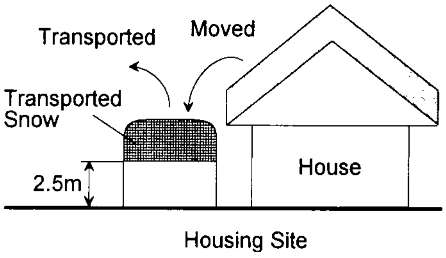

FIGURE 6 Model of housing sites with snow transportation demand.

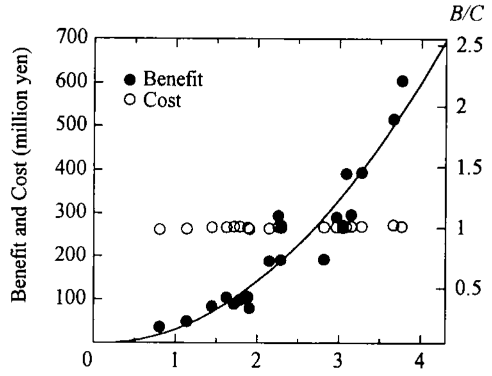

FIGURE 7 Benefit and cost of system versus annual maximum snow depth.

evaluated at 5 + 0.12N million yen a year, assuming that the pumps are operated 11 hr/day for snow cover days N. The sum of those costs, C, is calculated as

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

By using the snowfall and snow depth data for 20 years, from 1975 through 1994, the benefits, costs, and benefit-cost ratios of the snow-removing channel 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 2.77 m) and the second decade (1985–1994, 1.94 m) are 1.08 and 0.62, respectively.

Figure 7 shows the relationship between 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 3 m, the system has an annual benefit-cost ratio of more than 1, making the system economically effective.

Figure 8 shows the benefit B_1 and B_2 on roads, sidewalks, and housing sites in representative years of light (1991), average (1994), and heavy (1983) snowfall. Figure 8 indicates that B_2 is more than B_1, and the major factor in the benefits is housing sites. B_2 for housing sites

TABLE 3 Results of Benefit-Cost Analysis

	Snow Data		Results of Calculation			
Year	Maximum Snow Depth (m)	Snow Cover Days (days)	Benefit $B1$ (million yen)	Benefit $B2$ (million yen)	Cost C (million yen)	B/C
1975	2.82	126	44	149	268	0.72
1976	3.15	142	50	247	270	1.10
1977	3.09	131	46	345	269	1.45
1978	1.14	95	33	16	264	0.19
1979	3.05	104	37	235	266	1.02
1980	3.77	141	50	555	270	2.24
1981	1.79	129	45	53	269	0.36
1982	2.29	105	37	154	266	0.72
1983	3.67	166	58	458	273	1.89
1984	2.97	126	44	247	268	1.09
1985	3.28	140	49	345	270	1.46
1986	1.89	111	39	66	266	0.39
1987	2.15	102	36	153	265	0.71
1988	0.81	76	27	10	262	0.14
1989	1.91	87	31	49	263	0.30
1990	2.30	109	38	233	266	1.02
1991	1.45	113	40	44	267	0.31
1992	1.72	123	43	46	269	0.33
1993	1.63	119	42	62	267	0.39
1994	2.26	123	43	251	268	1.10
Total			832	3,718	5,346	0.85

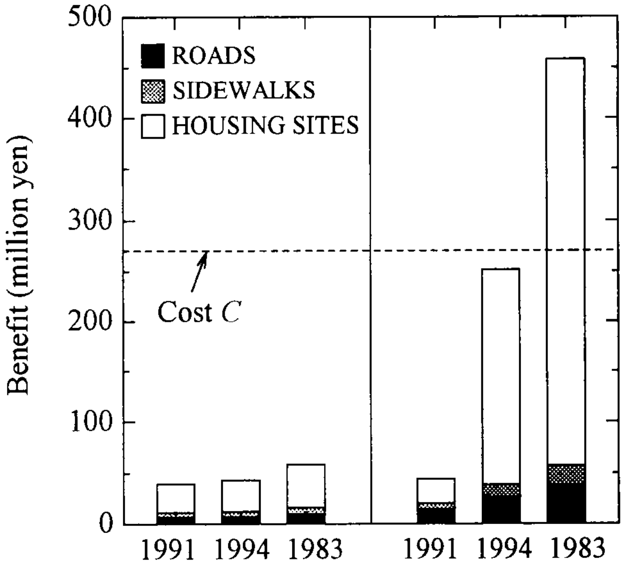

FIGURE 8 **Benefit B_1 and B_2 on roads, sidewalks, and housing sites in representative years.**

increases considerably with an increasing amount of snowfall. This is because the amount of snow transported by trucks increases dramatically as the frequency of roof snow removal increases. This characteristic of B_2 appears to determine the economic effectiveness of the system.

CONCLUSIONS

A method for evaluating the economic effectiveness of a snow-removing channel has been proposed and applied to the snow-removing channel system in Tokamachi City. The annual benefits, costs, and benefit-cost ratios have been calculated for 20 years, from 1975 through 1994, and conclusions were made.

First, the economic effectiveness of the system is dependent on the amount of snowfall. For example, the system is effective for the first decade (average $B/C = 1.08$) but not effective for the second decade (average $B/C = 0.62$). Second, the annual benefits B increase with the annual amount of snowfall, but the annual costs C are almost constant. The critical value for economic effectiveness ($B/C = 1$) is attained at an annual maximum snow depth of about 3 m. Third, the benefit B_2 is more than B_1. The major factor for B_2 is housing sites, and B_2 increases considerably as the amount of snowfall rises.

This method is applicable to other places for which a snow-removing channel is planned. It can contribute to the selection of the measures against snow damage.

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REFERENCE

1. Umemura, T., S. Kamimura, and H. Otaki. Snow Damage in an Urban Area with Heavy Snow Fall. *Journal of Natural Disaster Science*, Vol. 13, No. 1, 1991, pp. 1–11.