COST BENEFIT ANALYSIS OF ROAD SNOW REMOVAL PROJECTS: THEORY AND APPLICATION

Shin KIRIKOSHI
Snow Research Center, Inc., Japan
kirikoshi@yukicenter.or.jp

Masanori MIURA
Tohoku Regional Bureau, Ministry of Land, Infrastructure, Transport and Tourism
miura-m2r6@thr.mlit.go.jp

Kazuo Abe
Tohoku Regional Bureau, Ministry of Land, Infrastructure, Transport and Tourism
abe-k82aq@thr.mlit.go.jp

Junichi OSHIMA
Snow Research Center, Inc., Japan
junichioshima@yukicenter.or.jp

ABSTRACT

This study aims to 1) propose a microeconomic model for cost benefit analysis of snow removals, and 2) verify the practicability of that model using data measured at a section of national highways. To conduct cost benefit analysis using a microeconomic approach, we must first estimate the benefits and costs. We estimated the benefit using following procedure:

1) Assume two cases: with and without snow removal operation for a certain road condition.

2) Estimate traffic volumes for the two cases. The cost of transportation is estimated as the generalized cost (a sum of the transportation expenses and the monetary valuation of the time spent in travel). This paper focuses on the monetary valuation of the time spent in travel.

3) Estimate traffic volumes and generalized costs, and derive demand functions for the two cases. Assuming a quasi-linear utility function for the demand function, the benefit of snow removal is calculated as the difference in consumers' surplus between the two cases. This is the "consumers' surplus approach."

Using the model, we estimated the cost and the benefit of snow removal projects for the surveyed highway section for the two cases (with and without snow removal) and found that the model was practicable and that the benefits of snow removal greatly exceed the costs.

KEYWORDS

COST BENEFIT ANALYSIS / MICROECONOMIC MODEL / CONSUMER'S SURPLUS APPROACH

1. INTRODUCTION

This paper aims to examine whether cost benefit analysis based on microeconomic theory is practicable for evaluating the effects of road snow removal projects by applying such analysis to data collected for a national highway.
To carry out cost benefit analysis based on microeconomic theory, benefit and cost must first be determined. Benefit is calculated as follows.

a) Two scenarios are formulated: a "with removal" scenario in which snow removal is performed, and a "without removal" scenario in which snow removal is not performed.

b) For both scenarios, the traffic volume (transport demand) is estimated. The cost of transportation is estimated as the generalized cost (a sum of the transportation expenses and the monetary valuation of the time spent in travel).

c) From the traffic volume and the generalized cost, the demand function is derived. The benefit is calculated from the demand function. The utility function underlying the demand function is assumed to be quasi-linear. This assumption allows us to obtain the benefit as the difference in consumer surplus between the "with removal" and "without removal" scenarios. This is the consumer surplus approach in the cost benefit analysis based on microeconomics.

In this paper, the method of the cost benefit analysis based on microeconomics is reviewed in Chapter 2 and the practicability of such analysis is examined in Chapter 3 by applying it to data collected from a national highway.

2. BASIC THEORY OF COST BENEFIT ANALYSIS

2.1. Formulation

The optimizing behavior of road users as consumers can be formulated by maximizing the utility function shown in Equation (1) under the constraint of Equation (2).

$$U(z,x) = z + u(x) \rightarrow \max \qquad (1)$$

$$z + px = I \qquad (2)$$

Where,

U : quasi-liner utility function for consumers
z : numéraire goods with a price of 1
x : traffic volume
p : generalized cost (monetary valuation of time)

The maximized utility function of Equation (1) under the constraint of Equation (2) leads to Equation (3), which expresses the inverse demand function ($p = p(x)$).

$$\frac{\partial u(x)}{\partial x} = p(x) \qquad (3)$$

To conduct cost benefit analysis, the cost and benefit need to be determined. The benefit can be obtained by calculating the increase in social surplus as the sum of the increase in consumer surplus and in producer surplus.

2.2. Increase in consumer surplus (ΔCS)

Under the assumption that the utility function is quasi-liner, where the utilities of "with removal" and "without removal," are U_w and U_0 respectively, the change in consumer surplus, ΔCS, is expressed as the difference between the two utilities U_w and U_0, namely $\Delta U = U_w - U_0$. Thus, the change in consumer surplus, ΔCS, can be formulated as Equation (4).

$$\begin{aligned}\Delta CS = \Delta U &= U_w - U_0 \\ &= U(z_w, x_w) - U(z_0, x_0) \\ &= u(x_w) - p_w x_w - \{u(x_0) - p_0 x_0\} \\ &= u(x_w) - u(x_0) - (p_w x_w - p_0 x_0) \\ &= \int_{x_0}^{x_w} \frac{du(x)}{dx} dx - (p_w x_w - p_0 x_0) \qquad (4) \\ &= \quad (\Delta GCS) \quad - \quad (\Delta PQ)\end{aligned}$$

The first term in Equation (4) integrates the inverse demand function $p = p(x) = \frac{\partial u(x)}{\partial x}$ of Equation (3) in relation to the traffic volume, thus expressing the change in gross consumer surplus (ΔGCS), and the second term represents the change in payment or the change in cost required of users (ΔPQ).
According to the inverse demand function $p = p(x)$ in Equation (3), if $x=p^{-1}(p) \equiv D(p)$ is substituted for the demand function, the change in consumer surplus (ΔCS) can be expressed with Equation (5). From Equations (4) and (5), we derive Equation (6).

$$\Delta CS = \int_{p_w}^{p_0} D(p) dp \qquad (5)$$

$$\begin{aligned}\int_{x_0}^{x_w} p(x) dx &= \int_{p_w}^{p_0} D(p) dp + (p_w x_w - p_0 x_0) \qquad (6) \\ (\Delta GCS) &= \quad (\Delta CS) \quad + \quad (\Delta PQ)\end{aligned}$$

2.3. Change of producer surplus (ΔPS)

When $s_w(x)$ stands for the social marginal cost function of road use with removal and $s_0(x)$ without removal, the change of producer surplus (ΔPS) is expressed with Equation (7).

$$\begin{aligned}\Delta PS &= \left\{ p_w x_w - \int_0^{x_w} s_w(x) dx \right\} - \left\{ p_0 x_0 - \int_0^{x_0} s_0(x) dx \right\} \\ &= (p_w x_w - p_0 x_0) - \left\{ \int_0^{x_w} s_w(x) dx - \int_0^{x_0} s_0(x) dx \right\} \qquad (7) \\ &= \quad (\Delta PQ) \quad - \quad (\Delta SC)\end{aligned}$$

2.4. Benefit (= increase in social surplus) (ΔB)

For the benefit, which is defined as the increase in social surplus (= increase in consumer surplus + increase in producer surplus), Equation (8) can be obtained from Equations (6) and (7)

$$
\begin{aligned}
\Delta B &= \Delta CS + \Delta PS \\
&= (\Delta GCS - \Delta PQ) + (\Delta PQ - \Delta SC) \\
&= \Delta GCS - \Delta SC
\end{aligned} \tag{8}
$$

The above relation is illustrated in Fig. 1 and listed in Table 1, where (3)+(4)+(5)+(6) represents the benefit that is the change in social surplus.
If the both social marginal cost functions by road use, namely $S_w(x)$ and $S_0(x)$, are independent of the traffic volume , then they are horizontal, as Fig. 2 and Table 2 indicate, where (2)+(3) represents the benefit expressed in terms of the change in social surplus. In Chapter 3, the benefit is figured out on the basis of Figure 2 and Table 2, under the supposition that the social marginal cost is independent of the traffic volume *x*.

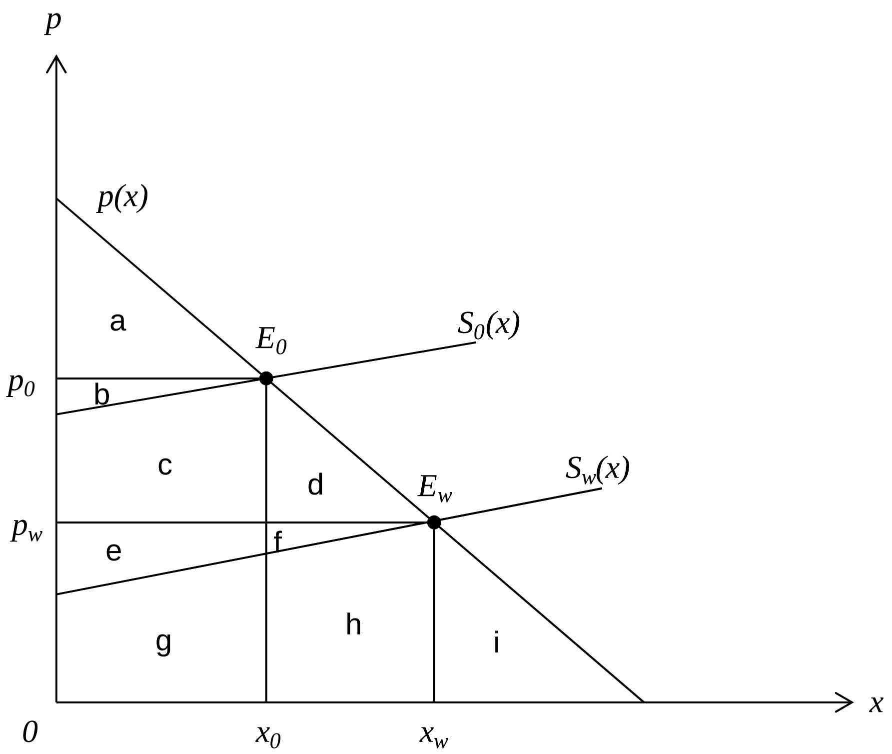

Fig. 1

Table 1

<table>
<tr><td colspan="3"></td><td>WITH REMOVAL</td><td>WITHOUT REMOVAL</td><td>WITH - WITHOUT</td></tr>
<tr><td rowspan="2">GCS</td><td colspan="2">CS</td><td>a+b+c+d</td><td>a</td><td>b+c+d</td></tr>
<tr><td rowspan="2">PS</td><td>PQ</td><td>e+f+g+h</td><td>b+c+e+g</td><td>f+h-b-c</td></tr>
<tr><td></td><td>-SC</td><td>-g-h</td><td>-c-e-g</td><td>c+e-h</td></tr>
<tr><td colspan="3">B</td><td>a+b+c+d+e+f</td><td>a+b</td><td>c+d+e+f</td></tr>
</table>

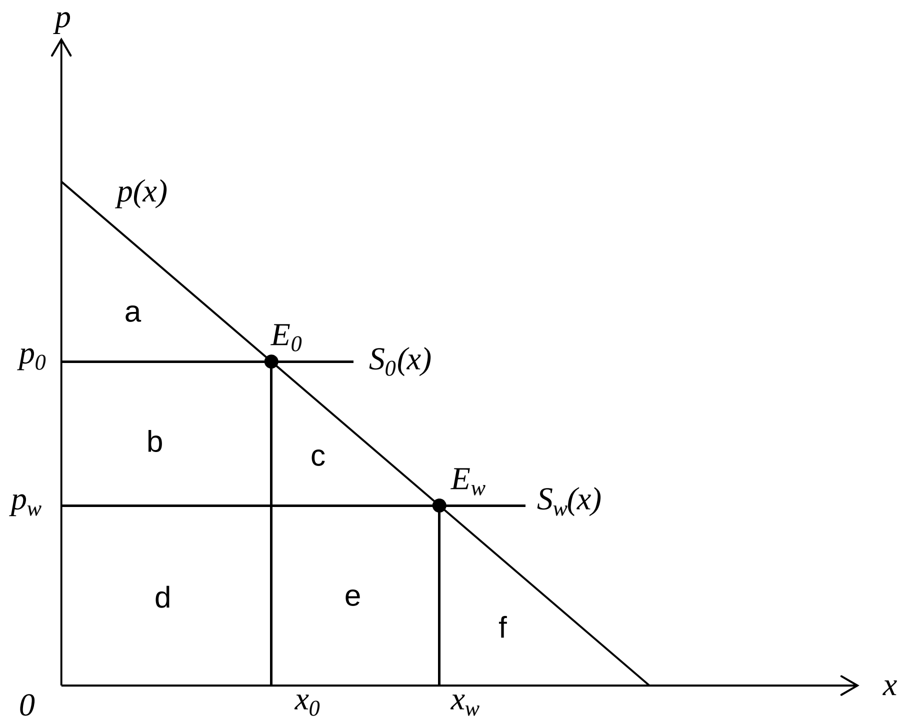

Fig. 2

Table 2

			WITH REMOVAL	WITHOUT REMOVAL	WITH - WITHOUT
GCS	*CS*		a+b+c	a	b+c
	PS	*PQ*	d+e	b+d	-b+e
		-SC	-d-e	-b-d	b-e
B			a+b+c	a	b+c

3. APPLICATION TO ROAD SNOW REMOVAL OPERATIONS

3.1. Tested road section

A section of National Route 4 in downtown Aomori City, Aomori Prefecture, was surveyed to examine whether it is practical to apply cost benefit analysis to snow removal operations. Aomori City, which is in one of the snowiest regions in Japan, had 444 cm of snowfall in 2008. The surveyed road section is 1.7 km (Fig. 3), with six traffic lanes (Fig. 4).

Snow removal was conducted on this section from the night of January 28 to the early morning of January 29, 2009. Photo 1 and 2 show snow on the road before (without removal) and after (with removal) the snow removal operation.

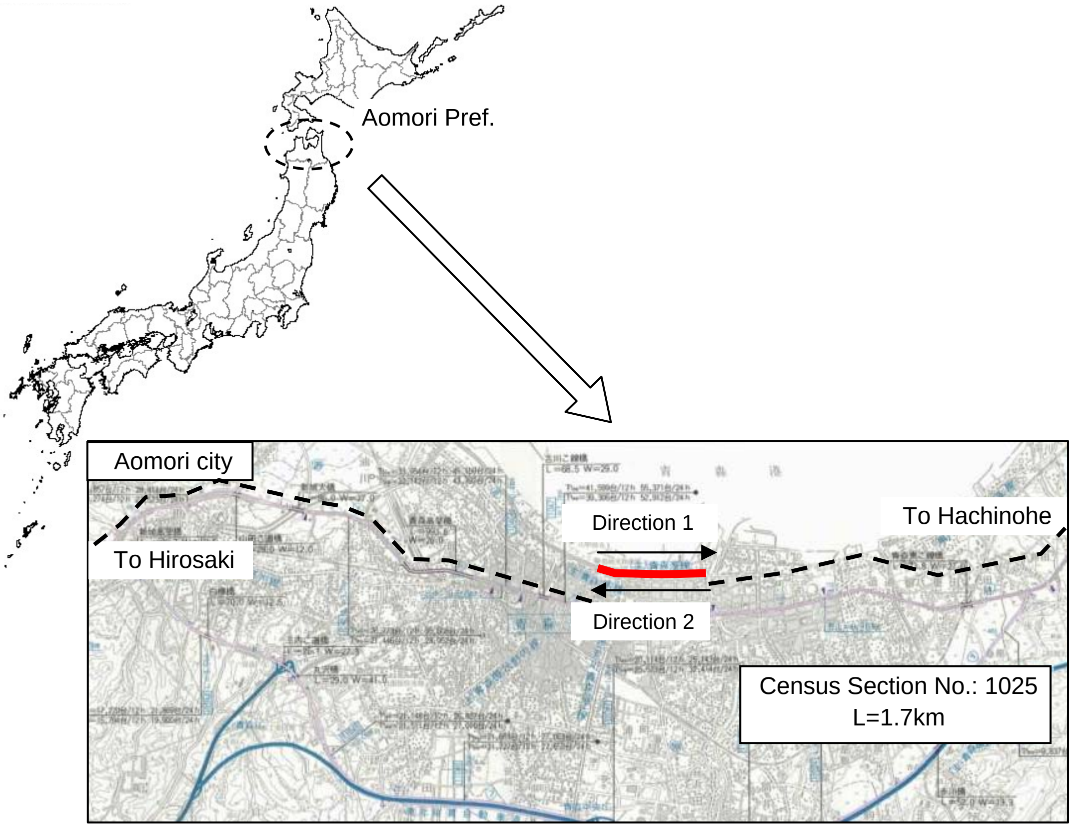

Fig.3. Location of the national highway studied

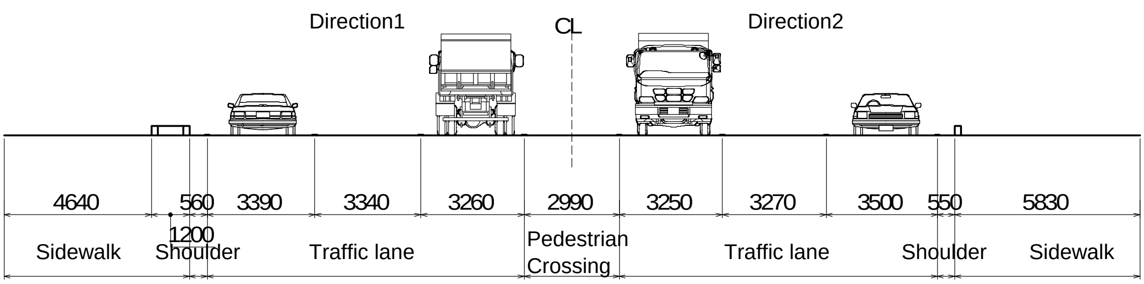

Fig.4. Lane width of the tested section
(near KP737.50 on National Route 4)

Photo 1. Snow on the road before snow removal (without removal)

Photo 2. Snow on the road after snow removal (with removal)

3.2. Survey result

Travel time (by direction), travel speed (by direction), and traffic volume (by direction and vehicle type) before snow removal (without removal, January 28, 2009) and after snow removal (with removal, January 29, 2009) are listed in Table 3. Table 3 reveals that the travel time was shortened (improved travel speed) and the traffic volume increased as a result of snow removal. In accordance with Figure 2 and on the basis of the time value saved for each vehicle type (Table 4), which is a factor generally employed by Japanese researchers in cost benefit analysis, the benefit is calculated as 1,568,000 yen per day. This is greater than the cost of snow removal for this section (1,273,000 yen), proving the cost-effectiveness of the snow removal operation.

Table 3. Cost benefit ratio (B/C)

			2009/1/28			2009/1/29						
			Travel time (s)	Travel speed (km/h)	Traffic volume (vehicles)	Travel time (s)	Travel speed (km/h)	Traffic volume (vehicles)	Consumer surplus (10,000yen)	Benefit (10,000yen)	Cost (10,000yen)	B/C
Vehicle type	Time zone	Direction	p_0		x_0	p_w		x_w				
Passenger car	12-h daytime	1	303	20.2	12,525	265	23.1	12,882	32.3	156.8	127.30	1.23
		2	395	15.5	11,811	325	18.8	12,433	56.7			
Bus	12-h daytime	1	303	20.2	591	265	23.1	608	14.2			
		2	395	15.5	494	325	18.8	521	22.2			
Regular-sized freight vehicle	12-h daytime	1	303	20.2	1,130	265	23.1	1,163	3.5			
		2	395	15.5	966	325	18.8	1,005	5.5			
Small-sized freight vehicle	12-h daytime	1	303	20.2	2,050	265	23.1	2,109	8.5			
		2	395	15.5	1,827	325	18.8	1,926	14.1			
All four types	12-h daytime	1	303	20.2	16,296	265	23.1	16,762				
		2	395	15.5	15,098	325	18.8	15,885				

Table 4. Time value

Vehicle type	Time value (yen / min. / vehicles)
Passenger car	40.10
Bus	374.27
Regular-sized freight vehicle	64.18
Small-sized freight vehicle	47.91

4. CONCLUSION

In this study the applicability of cost benefit analysis based on microeconomic theory to evaluation of the effects of road snow removal projects was examined by using data collected from a national highway.

The method was found to be sufficiently feasible for evaluating snow removal projects. The cost-effectiveness of snow removal operation was verified.