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Evaluation of the snow-removal options in an urban area based on the preferences of inhabitants

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ABSTRACT. Basically there are three kinds of snow removal: mechanical snow removal (MSR), snow-thawing pipe systems (STP) and snow-conveying open channels (SCOC). This paper identifies inhabitants' attitudes toward snow-removal options and quantitatively evaluates their preferences by applying the Analytical Hierarchy Process (AHP) method. A hierarchy is specified separately for the road in front of a house and the site of a house. A case study carried out for citizens living in the city of Ojiya in Niigata reveals that the space available for walking is an important factor, and hence STP scores considerably higher than SCOC and MSR. For the evaluation of a house site, the frequency per season of removing snow from a roof is the most important factor. House designs for overcoming snow accumulation are also evaluated.

INTRODUCTION

We have a very wet and heavy snowfall in the city of Nagaoka in Niigata prefecture, probably the heaviest snowfall in the world among cities with populations of more than 100 000. Technological development has made it possible to remove and dispose of snow from a road, but the snow accumulated on the roof and site of a wooden house is removed manually by its residents. Basically there are three kinds of snow removal: mechanical snow removal (MSR), snow-thawing pipe systems (STP) and snow-coveying open channels (SCOC). To meet citizen requirements, local government must decide which options are cost-effective or appropriate for each district in an ruban area. Snow-removal options have been empirically evaluated, but not by a scientific method.

The objectives of this paper are to identify the hierarchical structure of inhabitants' attitudes toward snow-removal options and to evaluate their preferences quantitatively by applying the Analytical Hierarchy Process (AHP) method. A hierarchy comprised of three main factors — environment, labor and cost — is specified separately for the frontage road of a house and the site and roof of a house.

SNOW-REMOVAL SYSTEMS

The term "urban snow disaster" has been used to describe problems such as disturbed transportation and overloaded houses caused by snow accumulation on valuable space. Another term, "overcoming snow", means disposing of snow from a valuable space. For example, when snow is removed not only from a road but also from a sidewalk, the level of service for overcoming snow becomes higher. Citizens in heavy-snow areas are asking for higher levels of service than ever before.

Modern technology for overcoming snow has been rapidly developed over the past thirty years in Japan. We have three basic systems for snow removal from a road: MSR by bulldozer or snow rotary, STP and SCOC. Although it is rather difficult to compare the total cost of facility (i.e. construction) and operation for the three options, a case study shows that the cost of MSR is rather low and similar to the cost of SCOC (assuming that labor cost of SCOC is excluded), but the cost of STP is much higher than the other two options. One of the technological and institutional problems for local governments is to secure a supply of river water for SCOC and a supply of underground water for STP.

Another and much more difficult problem for citizens in heavy snowfall areas is the removal of snow from a house roof to relieve the overload of the wooden structure. The snow fallen on a roof is usually dumped and removed manually by residents, and then the snow accumulated in a house site must be conveyed by truck or drained away by SCOC if an open space is unavailable in the site. Recently houses with structural features for overcoming snow have been introduced and are becoming popular. The snow-slipping type makes snow slip down a roof to the ground and usually has a first floor higher than 1.5 m. Another, the snow-thawing type, is equipped with a system for thawing the snow on a roof by electrical power or oil heating. The snow-thawing type is extremely expensive to build and operate.

ANALYTICAL METHOD

We apply the Analytical Hierarchy Process (AHP) developed by T. L. Saaty (1980) to evaluate the preference of inhabitants toward snow-removal options. The AHP can include and measure all important tangible and intangible, quantitative and qualitative factors. It also allows for differences in opinion and for conflicts, as is the case in the real world. Kinoshita (1986) is one of the applications of AHP in Japan.

The steps of the AHP for our problem proceed as follows.

(1) The problem is the evaluation of snow removal options: MSR, STP, SCOC and their combination. We separate the problem into snow removal from a road (the road in front of a house) and that of a house site (the site and roof of a house).

(2) The criteria for evaluating the problem are classified into three elements: environment of a road or site, labor required to remove and dispose of snow, and private cost of snow removal which inhabitants must pay.

(3) We structure a heirarchy of the criteria, subcriteria and properties of alternative options. Figures 1 and 2 show the hierarchy for snow removal from a road and from a house site, respectively.

(4) For elements of the lowest level in a hierarchy, we identify a utility function with a value between 0 and 100. The utility function represents a score of an alternative option with respect to an element of the lowest level. This step is our modification and differs from the method proposed by Saaty.

(5) The elements of the same level pairwise are compared in their strength of influence on the next higher level. Then, the matrix of pairwise comparisons is constructed and its eigenvalue calculated to obtain a set of weights in a hierarchy.

For the level which has more than three elements, the consistency index, CI, must be computed to examine the deviation from consistency of pairwise comparisons. The CI can be represented by $(\lambda_{\max} - n)/(n-1)$, where $\lambda_{\max}$ is the largest eigenvalue of a matrix of numbers, representing the judgement of pairwise comparisons, and n is the number of elements of the level in a hierarchy. The $CI \leq 0.10$ is considered acceptable.

(6) We obtain the composite score of an alternative option by summing up the multiplicity of the score of an element and its weight in the lowest level.

Let us denote the weight by W_i and the score of a utility function by S_i of an element i in the lowest level; then the composite score, CS, is

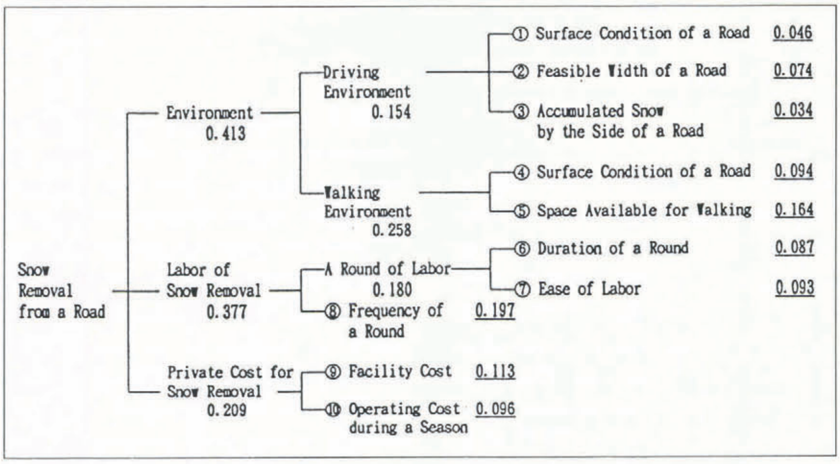

Fig. 1. Hierarchy and weights for snow removal from a road.

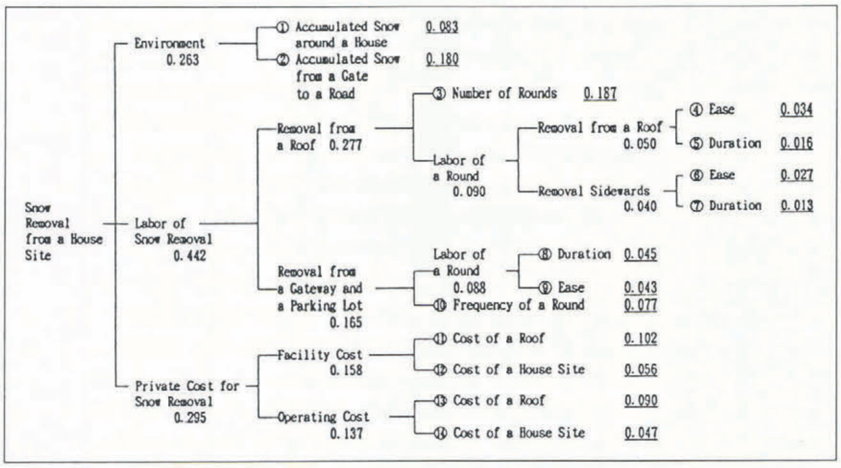

Fig. 2. Hierarchy and weights for snow removal from a house site.

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$$CS = \sum_i (W_i \times S_i), \qquad (1)$$

where

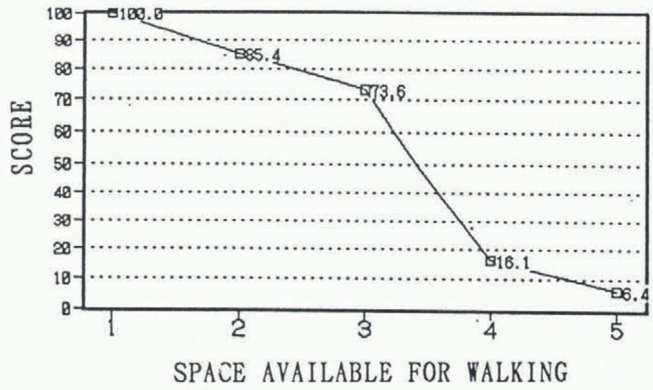
$$\sum_i W_i = 1.0 .$$

QUESTIONNAIRE SURVEY AND DATA

We selected the built-up area in the cities of Nagaoka and Ojiya for case studies and conducted a questionnaire survey of inhabitants there.

Both cities are located in the heavy-snow region, particularly Ojiya where the average maximum snow depth is about 2.5 m, which is deeper by 1.0 m than in Nagaoka. In Nagaoka, heavy snowfall has been overcome by snow-thawing pipe systems and mechanical snow removal. In Ojiya, snow-conveying open channels have been developed and successfully managed by the mutual cooperation of inhabitants.

This paper deals with the results of the case study in Ojiya. The questionnaire survey covered the built-up area on the west side of Shinano River, where the central and newly developed areas are located. The number of valid replies is 1023 for the questionnaire on road-snow removal and 1065 for the questionnaire on site-snow removal. The response rate was about 60%.



1	walk on a sidewalk in comfort
2	walk on a sidewalk
3	walk on a road in comfort
4	walk on a road with danger
5	difficult to walk on a road

Fig. 3. Utility function for the space available for walking.

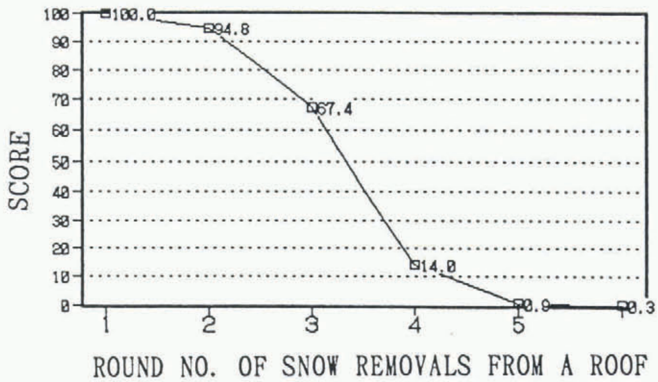


Fig. 4. Utility function for the round number of snow removals from a roof in one season.

RESULTS OF EVALUATION

The utility function

For the lowest elements in the hierarchy, we asked residents to choose one of the alternative situations such that "he/she can accept the situation, but cannot be patient with any worse situation". Then the cumulative-distribution curve of chosen situations yields the utility function of a lowest element, which shows the percentage score of a particular situation of a lowest element.

For example, Figure 3 shows the utility function for the space available for walking; the score is rather high when people can walk in comfort both on a sidewalk and a road. Figure 4 shows the utility function for the round number of snow removals from a roof per season; the score decreases sharply when the number increases from 2 to 3 times per season.

The weights of elements

Figure 1 also shows the weights of elements in the hierarchy of road-snow removal. The weight for environment is greatest (0.413), compared with labor (0.377) and cost (0.209). The second level shows that the walking environment (0.258) is more important than the driving environment (0.154). The space available for walking (Fig. 3) has a weight of 0.164. Both elements of labor in the second level are important factors, having almost the same weights (0.180 and 0.197).

Figure 2 shows the weights of elements in the hierarchy of a house site. The weight for labor is greatest (0.442), compared with environment (0.263) and cost (0.295). The second level shows that the labor of roof-snow removal is the most important factor (0.277), followed by the snowfall condition from front door to road (0.180), which is the lowest element of environment. Among the elements lower than the third level, the round number of snow removals from a roof per season is a very important factor (0.187), of which the utility function is already shown in Figure 4.

COMPOSITE SCORES

The composite scores for snow removal from a road

We compute the composite scores for a road under the assumption of several model cases. For the width and structure of a road, we set up two cases: 4 m wide without a sidewalk and 6 m wide without a sidewalk.

We consider four cases for snow-removal options: MSR only, STP only, SCOC only and the combination of thawing pipe and conveying open channels (STP +

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SCOC). In the densely built-up area of Ojiya where houses stand close together and roads are narrow, STP, SCOC or STP + SCOC are primary options. In the outskirts of the area, MSR is the only option for snow removal and SCOC has not been introduced. Therefore, the combination of MSR and SCOC is not considered in our analysis.

Additionally, we assume that the facility cost of snow-removal systems is zero.

Figure 5 shows the computed composite scores for eight cases. Even under a certain case of snow-removal options and road structure, it is appropriate to assume that the scores of elements in the lowest level can have a possible variability or uncertainty. For each case, we compute several composite scores assuming different and possible conditions of elements; the sensitivity of composite scores are shown by the arrows in Figure 5.

(1) Given the same road structure, MSR scores lower than STP, and STP + SCOC scores highest. The difference between MSR and STP mainly stems from the labor elements. MSR requires residents to shovel and remove the snow accumulated at the entrance by a bulldozer early in the morning. In addition, the possible road width and conditions for vehicle driving and walking reduce the score of MSR.

(2) STP scores considerably higher than MSR. This is because removal work becomes unnecessary and road environment improves, but on the other hand the electrical cost of operating pumps with STP does not reduce the score so much.

(3) SCOC scores higher than MSR, because road environment improves and removal work is simplified by throwing the snow into SCOC.

(4) Even under the same method of snow removal, the width of road affects the score considerably. This is because a wider road can supply more space for vehicles and pedestrians, and space availability implies higher scores for driving and walking environment.

(5) As we have already commented, walking environment is the most important element in the second level. Where the snow is cleared away, the road of 6 m width can contribute not only to vehicle driving but to walking space; but when a sidewalk of a wide road is covered with snow mechanically conveyed from the road, the sidewalk is no longer recognized to be valuable.

The composite scores for snow removal from a site

We also compute the composite scores of a house site under several model assumptions. First, snowfall strength or snow depth is represented by the round number of snow removals from a roof in a season, which is the number such that "he/she can accept, but cannot be patient with a worse situation". For a house site, two cases are specified: in case A open space is available to dispose of roof snow inside the site, and in case B open space is unavailable and snow removal by truck is necessary. A snow-removal option is assumed to be mechanical only when the two house designs for overcoming snow are considered: the snow-slipping type and the snow-thawing type.

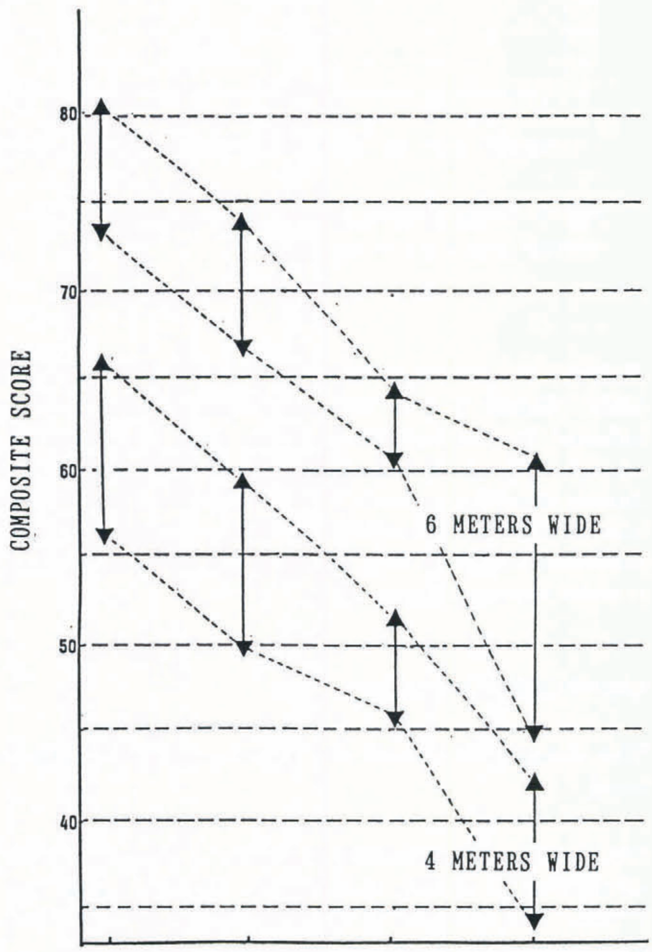

Fig. 5. Composite scores for snow removal from a road.

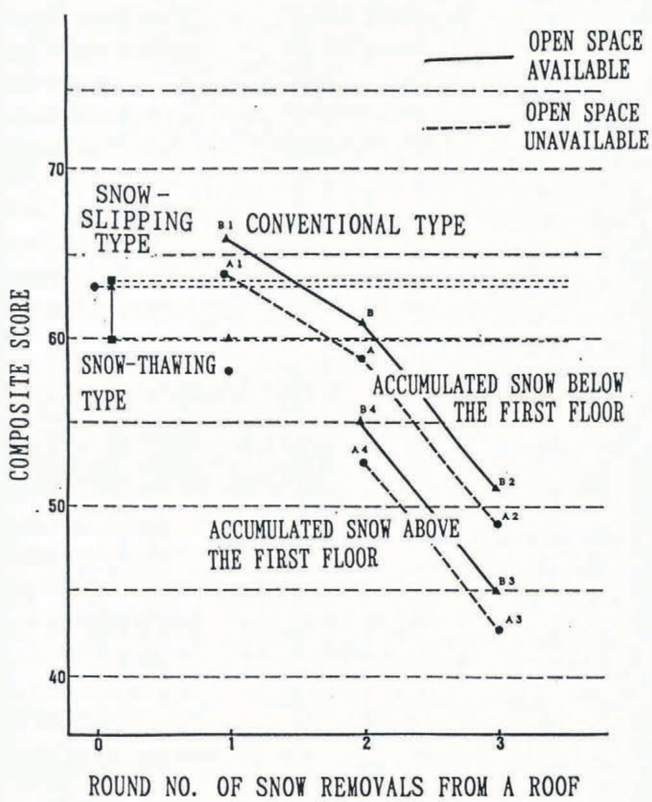

Fig. 6. Composite scores for snow removal from a house site.

The composite scores of a site vary substantially, depending on the round number of snow removals from a roof per season. The composite scores are shown in Figure 6; the horizontal axis is the round number of snow removals from a roof.

(1) The score decreases when the round number increases, particularly marginal rate is higher when the number increases from 2 to 3 times. The score of "open space available" is higher than "open space unavailable"; both are influential factors in labor.

(2) The snow-slipping type of house is assumed to cost ¥4 × 10^6 for construction. The snow-thawing type is assumed to cost ¥3 × 10^6 for construction and ¥5 × 10^4 for operation per season. Both the snow-slipping and snow-thawing types contribute to increasing the score of labor, but decreasing the score of cost.

(3) When the round number of snow removals from a roof is 1 per season, the snow-slipping and snow-thawing types of house have almost the same scores as a conventional (non-overcoming) type. When the round number of removals increases to 3 times, the score of a conventional house drops very low, while the slipping and thawing types keep the same scores as before.

CONCLUSIONS

We apply the method of Analytical Hierarchy Process to evaluate inhabitants' attitudes toward snow-removal systems, and hence measure the composite scores of snow-removal options under a variety of conditions. A case study carried out in the city of Ojiya reveals the following.

(1) Snow-thawing pipe systems make the composite score considerably higher than mechanical snow removal.
(2) Snow-conveying open channels make the score higher than mechanical removal for a road of < 6 m width, but lower than the snow-thawing pipe systems.
(3) Space available for walking contributes to increasing the score of environment, which does not depend on whether pedestrians use a road or a sidewalk.
(4) The round number of snow removals from a roof per season is an influential factor in the composite scores of a house site.
(5) When the round number of snow removals from a roof is 1, the snow-slipping and snow-thawing types of house have the same scores as a conventional type.

The evaluation method proposed in this paper has some aspects which should be studied further. First, the amount of snow which is removed and conveyed from a house site must be measured accurately, and the effect of its conveyance must be evaluated in the context of environment, labor and cost. Secondly, the evaluation of snow-removal systems must be made comprehensive by including other factors such as the cost of facility improvement, and the technological and local constraints of introducing new sytems.

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