SNOW AND ICE CONTROL SYSTEMS

FOR JAPANESE EXPRESSWAYS

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Abstract

Snow and ice control is generally implemented by mechanical equipment. Japan Highway Public Corporation (referred to as JH below), responsible for construction and management of expressways, uses about 1,000 snowplows and 500 anti-icing chemical spreaders for around-the-clock highway maintenance. Annual costs of snow and ice control on expressways amount to 200 million dollars. As anti-icing chemical, 150 to 200 thousands of tons of sodium chloride are used annually. With an increase of the length of expressways to be managed, JH has been requested to control road surface more efficiently during winter.

This paper outlines systems aimed at increasing the efficiency of snow and ice control during winter, and reports the status of system development. The snow and ice control systems produce various benefits as (i) level of service improvement, (ii) uniform work setup, (iii) cost reduction, and (iv) minimization of environmental impact.

1. Introduction

Japan has a national plan to build an 11,520-km expressway network, of which 6,850 kms has been already opened to traffic. The construction and operation of the expressways are the responsibilities of the Japan Highway Public Corporation (JH), which is a governmental organization. About 50% of the expressways in the network run through snowy and cold regions (with an average maximum snow depth of 30 cm or more). Even other areas, most routes are affected by snowfalls several times a year. For snow and ice control on expressways, grasping and predicting ever-changing weather and road conditions, and carrying out the right work at the right time are very important. JH has been studying various systems for application to efficiently reduce obstacles to traffic due to snowfalls or freezing on road surfaces. This paper outlines winter highway maintenance systems on the expressways in Japan, and presents an overview of a system aimed at increasing the efficiency of and sophisticating snow and ice control work and the status of its development.

2 Winter weather in Japan

Japan is an island nation and the location and winter monsoon causes considerable amount of snowfall. In some regions in the Hokuriku area, precipitation reaches as high as 1000 mm during winter (from December to April). Located at north latitudes of 30 to 45 degrees, the country receives ample sunlight even during winter, so the snow that accumulated on sunny roads are frequently subjected to an alternation of daytime melting and nighttime freezing. As a result, the surface condition fluctuates so substantially at different times and places that surface maintenance is difficult during winter.

3 Present winter highway maintenance and problems

(1) Winter highway maintenance by JH

JH has snow and ice control bases at spacings of each 60 to 100 km, and work yards at spacings of 10 to 20 km on expressways for collecting data and controlling work around the clock. Figure 1 shows the length of expressways that are maintained and the snow and ice control cost (1dollar=125yen). The cost of snow and ice control on expressways tends to increase with the length of expressways in service. Thus, more economical and efficient management of snow and ice control work is required.

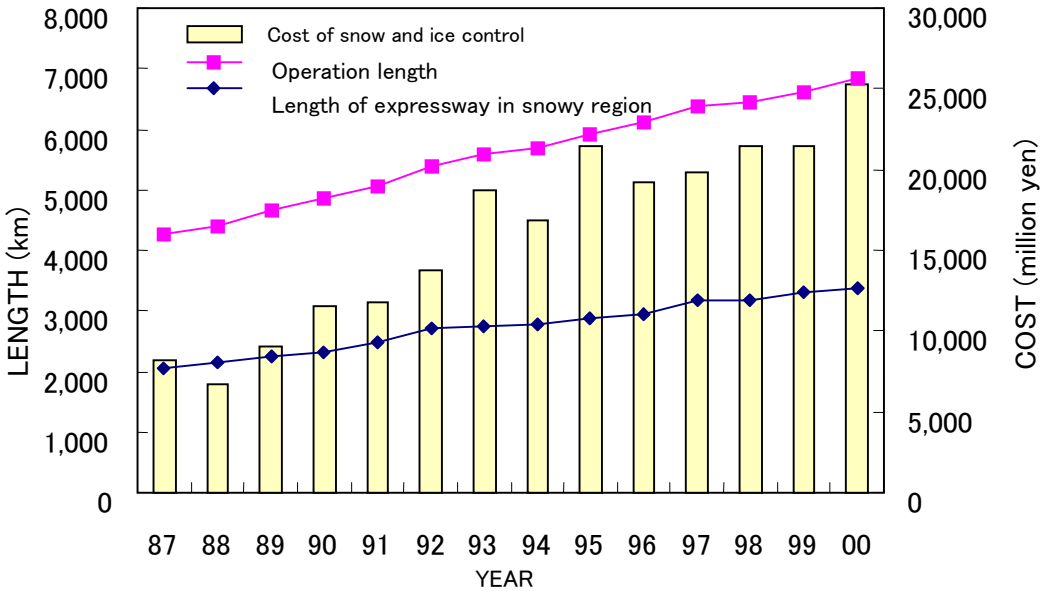


Figure1 Expressway Length in Operation and Cost of Snow and Ice Control

(i) Collection of meteorological data and weather forecasting

Collection of meteorological data and weather forecasting are important to decision making for establishing snow and ice control systems and for carrying out control work. For collecting meteorological data, meteorological observatories have been installed along the road (Table 1), and the data is transmitted to a base station via optical fiber cables. Surveillance vehicles also gather data.

For wide-area meteorological data, meteorological consultants are commissioned for regularly obtaining synoptic meteorological information and regional snowfall forecast data on-line or by fax. Meteorological data available along expressways is transmitted to meteorological consultants on-line as supplementary information for wide-area weather forecasting.

Table 1 Meteorological Observation Systems

	all of Japan		cold regions		other regions	
	quantity	interval (km)	quantity	interval (km)	quantity	interval (km)
Systems	829	8	292	8	537	8
surface temperature thermometer	962	7	453	5	509	9
air temperature thermometer	765	9	277	8	488	9
rain-gauge	740	9	260	9	480	9
wind meter	678	10	259	9	419	11
rainfall sensor	545	12	198	11	347	13
visibility meter	91	19	3	12	88	26
back-scatter type visibility meter	263		178		85	
ITV equipment	385	17	93	24	292	15

*March,2000

(ii) Snow removal work

Echelons of a few high-speed snowplows repeatedly remove snow on unidirectional two lanes to keep the surface snow below approximately 5 cm in depth. Packed snow is removed by truck graders or motor graders.

Removed and accumulated snow on shoulders is shot by rotary plows off from the carriage way. When the snow is on a bridge or an overpass and cannot be shot because there are houses nearby, the snow is transported on dump trucks to snow dumping sites. Snow removal work is contracted to local private companies and carried out under the supervision of JH.

(iii) Anti-icing measures

Anti-icing measures are an important component of snow and ice control measures in mountain areas because snow melts during the day and freezes at night frequently. A major anti-icing measure is spreading sodium chloride by vehicles. Pre-wetted salt is mainly spread, and salt solution and dry salt are also applied. The quantity of anti-icing chemicals used on expressways, which is affected by the meteorological conditions, ranges approximately from 150,000 to 200,000 tons per year (eight tons per lane per km).

In the steep-sloped sections on the carriage ways or interchange ramps, stationary solution-spreading equipment is adopted, for which the anti-icing chemicals that were spread are collected and re-used for minimizing environmental impact. At toll plazas and tunnel entrances and exits, where snow removal with equipment is difficult, snowmelting equipment is used to prevent freezing (Table 2).

Table2 Snowmelting Equipment

snow melting equipment by water sprinkling	261
road heating	498
snow melting equipment by road heating method	64
solution spreading equipment	59km (re-used:23km)

*March,2000

(2) Problems in winter highway maintenance

The primary obstacle to a smooth flow of traffic on expressways during the winter is their "closing to traffic". The causes of expressway closing in the past three years are broken down in Figure 2. The figure shows that about 65% of incidents of expressway closing all over Japan (26,755 hours per year) are ascribable to "unfavorable meteorological conditions", of which 60% was "caused by snow". The incidents of highway closing due to snow are classified into two major categories: disadvantageous surface conditions and obstruction to visibility. Minimizing the deterioration of surface conditions requires thorough snow and ice control measures such as snow removal and spreading of anti-icing chemicals. The work has been dependent on the judgement of experienced workers because it dealt with weather, which fluctuates drastically with time and place. With the expected increase in the length of expressways in service, plans are being studied to develop a system for work based on scientific judgement considering more data instead of depending on experienced workers. For controlling the obstruction to visibility due to snowstorms and drifting snow, a convoy system has been introduced in which a maintenance vehicle with special equipment leads ordinary vehicles in an echelon.

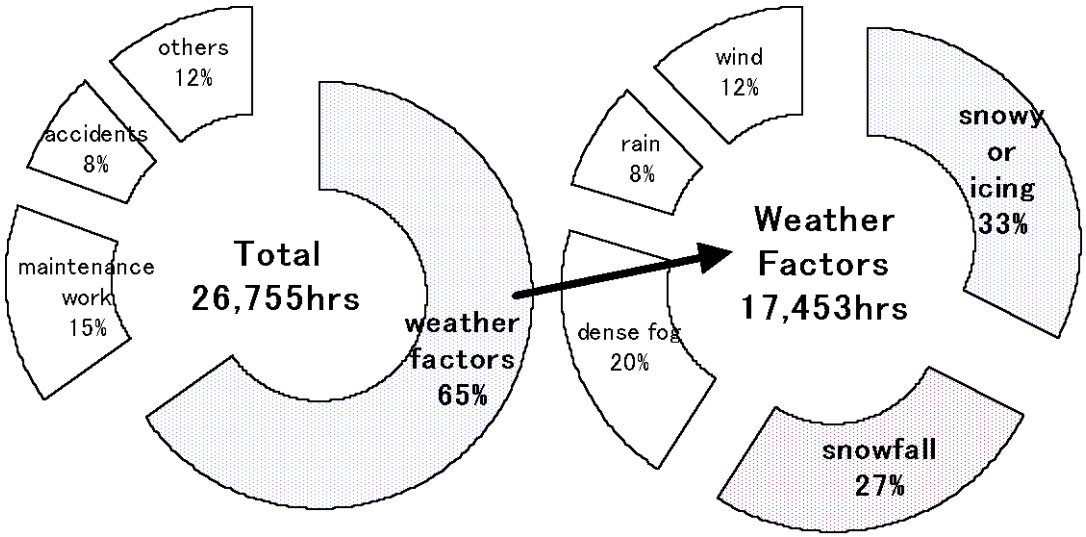


Figure2 Causes of Road Closure of Inter-urban Expressways('97-'99)

4 Goals of JH's winter highway maintenance system

The goals of JH's winter highway maintenance system are as follows.

(i) Improvement of service level

Road surfaces will be made more comfortable to drive on and incidents of closing will be reduced by enabling quick and appropriate work.

(ii) Uniform work setup

Mechanization and automation will be introduced according to the work by systematizing work (by using work patterns).

(iii) Cost reduction

The cost of snow and ice control work will be reduced by increasing efficiency, and enabling post assessment of work by data analysis by a system.

(iv) Minimization of environmental impact

Environmental impact will be minimized and impact on highway facilities will be reduced by using an optimum quantity of anti-icing chemicals.

5 Development of a system that supports winter highway maintenance

JH has been carrying out research and development of various systems for "more efficient winter highway maintenance" and conducting verification tests on actual highways.

JH's winter highway maintenance system consists of four phases: (i) collection of meteorological data on highways, (ii) forecast of changes in surface condition, (iii) control of snow removal work and (iv) automatic recording of work. JH is developing a system for each phase for incorporation into a integrated system.

(i) Collection of meteorological data on highways

An in-vehicle sensor is being developed as a sophisticated surface sensing technology. The in-vehicle sensor can continuously capture the surface condition, salinity concentration and surface temperature.

(ii) Forecast of changes in surface condition

For wide-area weather forecast, information is obtained from commissioned meteorological consultants. Meteorological data available along expressways are transmitted to meteorological consultants on-line to increase the accuracy of subsequent forecasting .

For weather forecast for narrower areas, surface temperature is forecasted using the data obtained in the past five years by observation, for multiple regression analysis.

(iii) Control of snow removal work

Operations of maintenance vehicles are controlled by GPS (global positioning system) to remove snow according to the specific surface condition. Control by GPS

enables easy grasp of current work conditions.

(iv) Automatic recording of work

The routes that vehicles followed for removing snow or spreading anti-icing chemicals, and the timing and details of work can be stored automatically.

How the winter highway maintenance system works is shown in Figure 3.

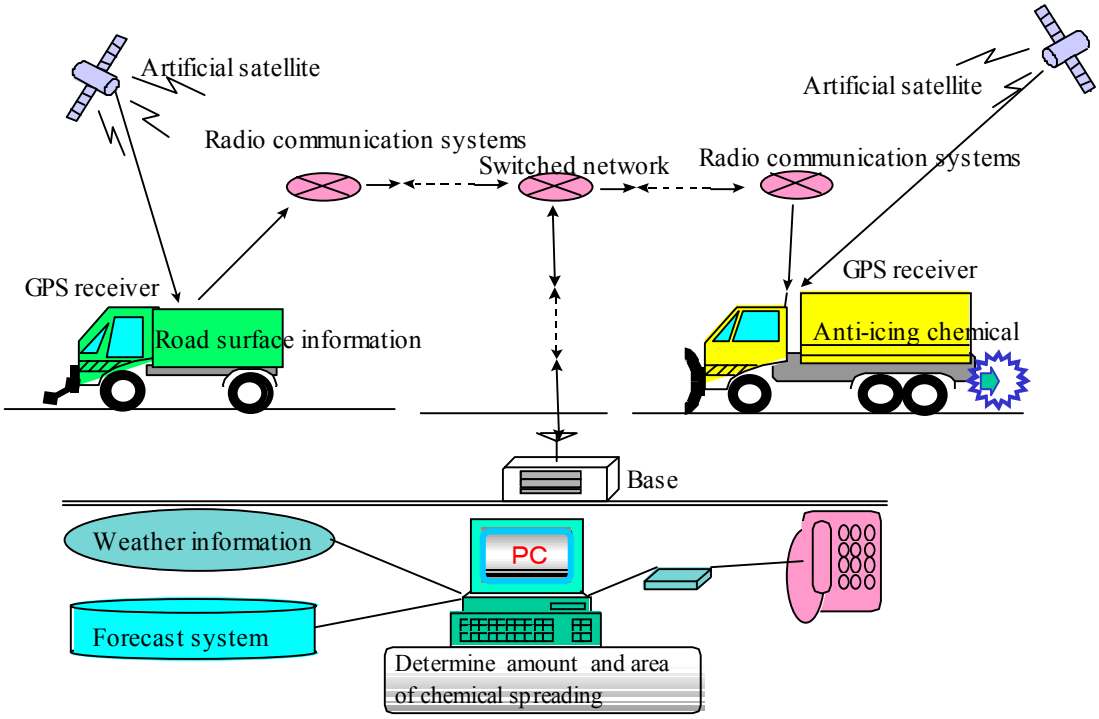


Figure3 Maintenance Vehicle Operation Control System

a. The sensor mounted on a maintenance vehicle continuously monitors the surface condition.
b. The surface condition data obtained are related to the position data collected by GPS.
c. The related data mentioned in b. are transmitted to the base station real-time via a highway-vehicle communication system.
d. Then the base station forecasts subsequent weather and freezing considering the field condition.
e. Work instructions are given to maintenance vehicles according to the forecast.
f. Maintenance vehicles carry out work while confirming their position by GPS.
g. Work details are transmitted to the base station for compiling work records.

5.1 Collection of meteorological and surface condition data

At present, meteorological observation apparatus installed at fixed points are used and visual observations are made from maintenance vehicles for obtaining meteorological and surface condition data. These means, however, entail the following problems.

(i) The meteorological observation apparatus obtains data only at installed points, so numerous units would be required to cover entire highways that have varying structures and are
influenced by insolation, leading to increased cost.
(ii) Visual observation from moving vehicles can hardly find out the condition where the visibility is low, and judgement may produce vary due to the experience of the worker. No digital data are available, so neither data bases nor systems can be developed.
(iii) Hand-held salinity concentration meters are used for verifying the lasting effect of anti-icing chemicals. Workers get out of the vehicle and take measurements on the expressway, which may make workers to face danger.

In view of the above, JH is now developing an observation vehicle as a system for collecting winter surface data (Photograph 1). Three types of sensors (for surface condition, surface temperature and salinity concentration) are mounted on the maintenance vehicle to enable the continuous linear find out of surface conditions, verification of lasting effects of anti-icing chemicals, quantitative identification of surface conditions and development of a data base.

Phot1 Continuous Surface Observation System

a. Surface condition sensor

The surface condition sensor radiates infrared pulsed laser to the surface, captures dispersed or reflected light, and determines the dryness, wetness, freezing, snow or slush on the surface. The sensor is developed by improving the stationary surface freezing detector for use on vehicles.

b. Continuous salinity concentration measuring equipment

The equipment samples the water splashed by traveling vehicles, and measures the salinity concentration remaining in the anti-icing chemical. The equipment is developed by improving the equipment for measuring the salinity concentration of sea water for use on vehicles. Electromagnetic measurement is adopted (the electric conductivity of solution is measured without contacting). Temperature correction is applied for measurement because electric conductivity varies depending on the

temperature. For preventing the freezing of the salinity concentration sensor, the heat source for the radiator is used.

c. Infrared thermometer

The thermometer, which is developed by improving the existing low-temperature infrared thermometer for use on vehicles, captures the amount of infrared radiation from the surface and measures the temperature on the surface. The measurements are compiled into a "thermal map".

5.2 Forecast of meteorological changes

The surface temperature (freezing) forecasting system that JH is currently implementing is outlined in Figure 4.

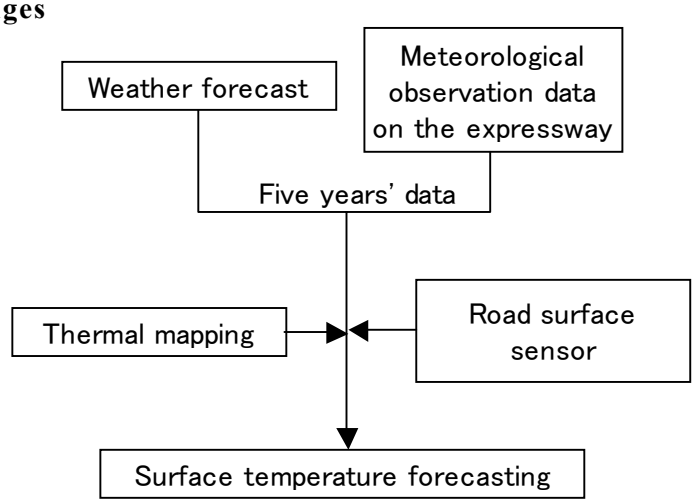


Figure4 Surface Temperature Forecasting System

The system forecasts hourly changes in surface temperature from evening (17:00 hours) until morning (9:00 hours) (long-time forecast), and for three-hour periods (short-time forecast). The long-time forecast assists the establishment of a system for spreading anti-icing chemicals, and the short-time forecast helps determine the timing of chemical spreading.

Sample results of surface temperature forecasting are shown in Figure 5. The results were generally satisfactory although the accuracy was low early in the morning

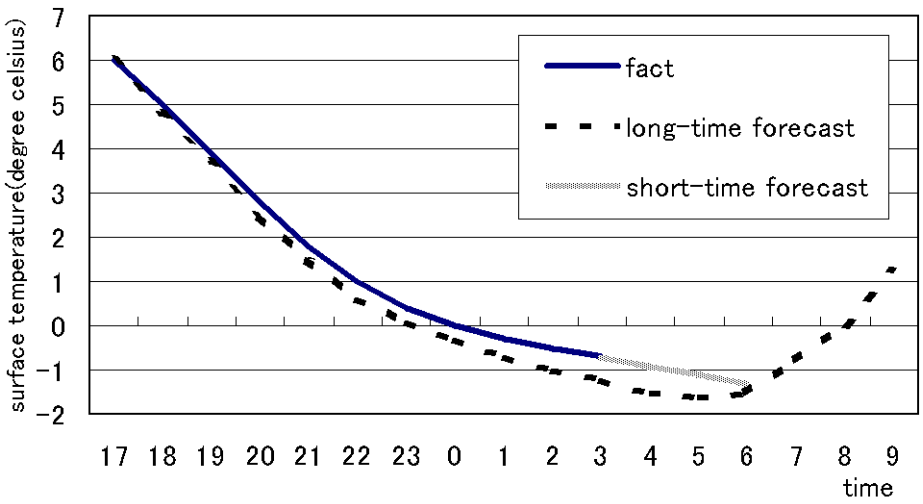


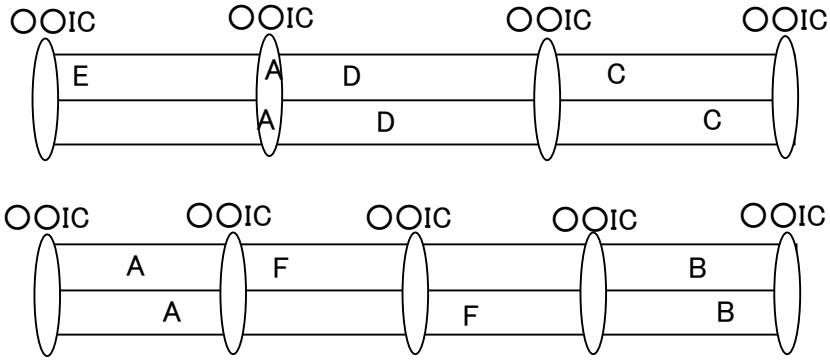
Figure5 Surface Temperature Forecasting System

because of the insolation. The system uses a statistical method based on the past data, so the accuracy decreases whenever the meteorological condition changes. The low accuracy is offset by short-time forecasting. At present, use of weather forecast data (GPV (grid point value) data) or physical models (heat balance models) are planned.

In order to forecast overall meteorological phenomena (weather) so as to meet the needs of road administrators, forecasting mechanism that considers regional characteristics is now being analyzed. Equipment for meteorological observation is also being enhanced according to the need.

5.3 Control of the operation of maintenance vehicles

Offices with numerous snow and ice control vehicles cannot completely control them manually on paper. The maintenance vehicle operation control system using GPS is therefore adopted. The system presents the type of work and the position of the vehicle to the control office via a GPS receiver on a snow and ice control vehicle. Radio communication dedicated to highway maintenance is used for data transmission. Digital communication will soon be made possible throughout Japan. The control office displays the status of vehicle operation on the monitor (Figure 6) and automatically compiles work records. The system can accommodate a maximum of 200 vehicles.



A: snow remover, B: compacted snow remover, C: chemical spreader, D: brine spreader, E: rotary, F: patrol

Figure6 Vehicle Movement Management System

6 Conclusions

This study presented an approach to the development of a winter highway maintenance system. At present, respective systems are being developed separately. Integrated system operation is expected to enable rapid deployment of vehicles and thus minimize the incidents of highway closing. An overall image of the system is given in Figure 7. Establishing the maintenance vehicle operation system would enable intelligent and sophisticated work, and snow and ice control work fit for the field condition.

For making the winter highway maintenance system more effective, creating an operating environment through the coordination of the four groups shown in Figure 8. People, highways and vehicles should be integrated into one through coordination among the drivers, police, vehicle and tire manufacturers, and highway administrator (JH). To this end, JH has been also emphasizing public relations. Further efforts will be made to increase the confidence in highways by securing smooth traffic flow on highways during winter.

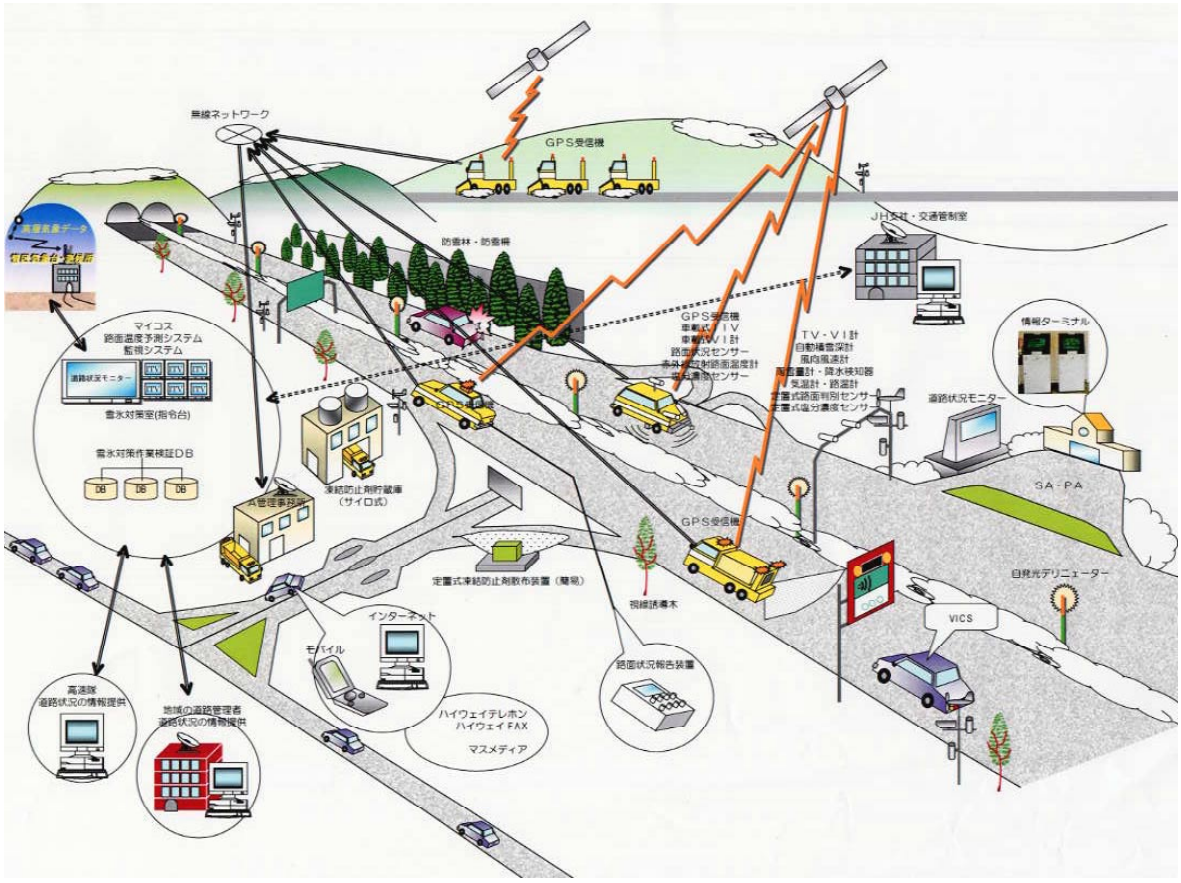


Figure7 Image of Snow and Ice Control Systems

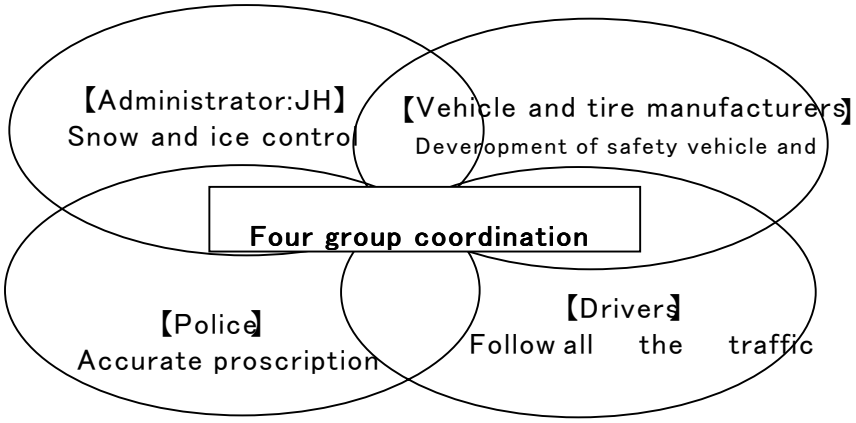


Figure8 Maintaining Smooth Traffic Flow in Season