DEVELOPMENT AND PRACTICAL USE OF THE WINTER ROAD-SURFACE MONITORING SYSTEM

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1. Abstract

Recently, it becomes a problem that the deicing/anti-freezing agents (Agents) spread over a road have an influence on the environment. And it is demanded to reduce the amount of the Agents used in the winter road maintenance. But as the winter road-surface conditions are changeable, it is very difficult to spread the suitable amount the Agents for the road condition timely. In order to solve this problem, our company which is the manufacture of Agents, has tried to research and develop the winter road-surface monitoring system from 1989.

Features of our system are as follows;

[1] Road condition data such as an air temperature, a road-surface temperature, snowfall and pictures of the road can be displayed on the same screen of a personal computer on real time.

[2] With the buried sensor below the road, we can get the changing concentration of the Agents (i.e. road-surface freezing temperature).

[3] By the picture on the display, we can know the changing condition of the road every moment.

[4] We can improve the reliability of weather forecasts to link our System to the other weather forecast system.

Our System installed in Morioka-city from 1998 to 2000 demonstrated the following effects.

[1] From various data of our system, the spreading amount of the Agents and the spreading time could be optimized; as the result, the amount of the Agents spread could be reduced.

[2] By installing the winter road-surface monitoring system at the city hall and the companies consigned spreading and sharing information of the road conditions each other, the good management of winter road could be attained.

[3] As a result of using our System, the expense of spreading the Agents could be cut down about 20%.

2. Introduction

In Japan, “the law concerning the prevention of spike tires dust” was announced and enforced in 1990, and use of the spike tire was prohibited. Since then, because of spreading stud less tires, the road being easy to slip, there has been increasing traffic accidents and traffic congestion. (Ref.1).

Consequently, the amount of the Agents sprinkled on the road has increased sharply and we are anxious about rising cost and environmental influence by the Agents. Therefore, the means in order to sprinkle effectively and also to decrease environmental influence is the urgent problem which each local government face. Under such conditions, as one of the solutions, our company was hoping to support the optimum Agents sprinkle based on the knowledge we have gained through the development of deicing salts, we have tackled research and development of the winter road-surface monitoring system.

In Europe and North American countries, Road Weather Information System had equipped on a national scale since the second half of the 1980s (Ref. 2) and the road management system is established by utilizing that system. Moreover not only the ground weather but also many sensors buried under the road are installed as the road weather data support as well. (Ref. 3). The road-surface sensor can detect not only road-surface temperature but also road-surface conditions and remains Agents concentration. This detected data is utilized as the basic data for spreading Agents on a road (Ref. 4).

In Japan we have also tried to establish the road management system in order to keep safety condition of the road in winter. (Ref1.5) The main data in Japan supporting this system is gathered from camera installed on the road, ground weather and temperature of rode surface, however, in terms of establishment of Road Weather Information System by using road surface sensor that can get information of the road condition and remains Agents concentration accurately Japan is falling behind Europe and North American countries.

This paper reports about the scheme of the Winter Road-surface monitoring system using buried sensor to detect road-surface condition and remained Agents concentration, and its cost performance.

3. The scheme of winter road-surface monitoring system

3.1 System Configuration

As shown in Fig 1, we located the local stations at several points of the management zone (decided with consideration of weather conditions) to collect road weather data. The data collected there will be gathered together at the main observation base, which manages the data, and will be sent to sub-station-monitoring base station. An example

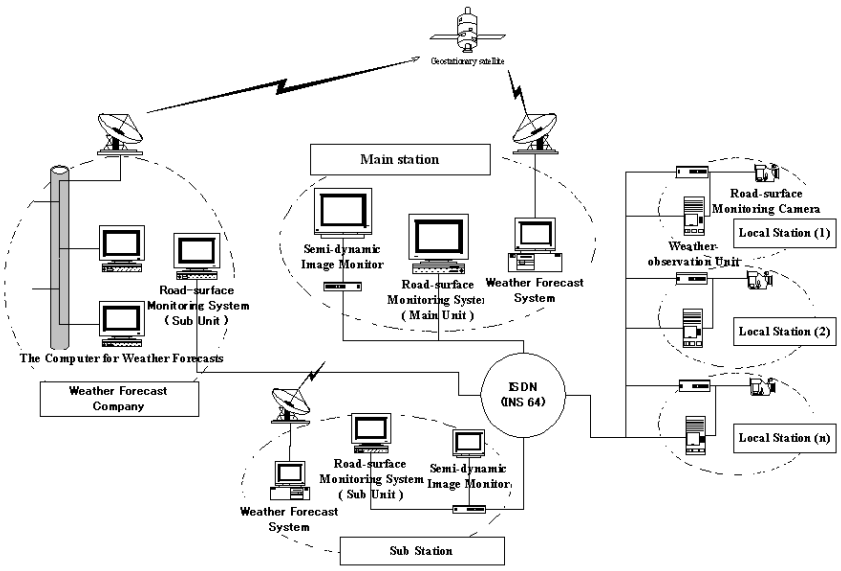

Fig.1 System Configuration

of the location for installation of main base point is Road Management Dep. Also, an example of the location of sub-station is the Agents sprinkle company or a weather forecast business corporation, etc.

3.2 Data-Communication Flow of System

The data-communications flow is shown in Fig.2.

A meteorological data on the road is collected from each sensor in weather station ROSA (made by Vaisala Ojy, Finland) installed in the local station. The data output from ROSA is including digital data and status data. Status data is the result of calculation in ROSA.

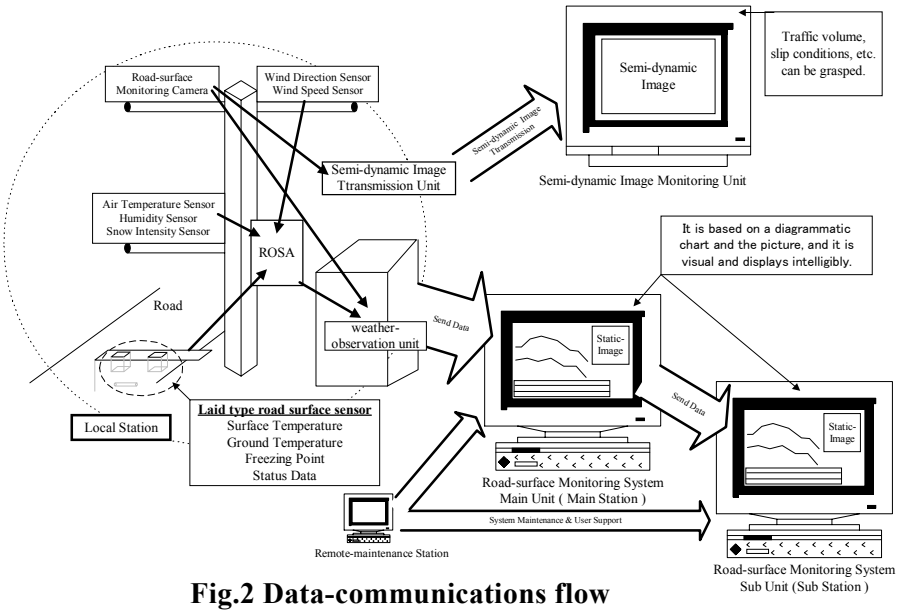

Fig.2 Data-communications flow

The character of each data is shown as below.

Numeric data

(1) Air temperature

(2) Road surface temperature

(3) Underground temperature (4) Snow fall (mm/h)

(5) Freezing point (calculated from the remains of the Agents on the road)

(6) Humidity (7) Dew point (8) Direction of the wind (9) Wind velocity

Status data

(1) Warning (2) Weather condition (3) Road-surface status

The data gathered from ROSA is collected in the weather-observation unit supported by our company every ten minutes. At the same time we can get the full color picture from a road-surface monitoring camera. This picture can be displayed at the resolution of 640x480 dots.

The data collected in the weather-observation unit in each local station is sent to sub station.

In this system, not only the data from ROSA but picture with high-resolution are also collected simultaneously and the numeric data, status data, and the picture are displayed on a same monitoring screen. Thus, we can pass the correct judgment by completing each data even under the difficult situation. The sensor of ROSA buried under the road can monitor road-surface condition (freeze, dryness, etc.) and remaining Agents on the road. Therefore it is possible to control sprinkle of Agents effectively.

Moreover, because semi-dynamic image can also be displayed through a semi-dynamic image electrical-transmission unit if needed, the dynamic status (slip status, traffic volume and so on) of a site, which is hard to judge, can be provided through this system.

TCP/IP is extensively adopted as a data-communication protocol. The data-transfer protocol adopted FTP and HTTP that are generally used on the Internet. Therefore, it is easy to connect to Internet. Therefore, we are conscious of the concept “Open” and it is easy to share the data from other systems. (Other road-surface monitoring system, RWIS, ITS, weather forecast system, etc)

3.3 Outlook of local station and screen of system monitoring

The example of install of a local station is shown in Fig.3. Moreover, two monitoring screen are explained as an example of a main monitoring screen.

(1) Air Temperature screen (Fig. 4)

Five data such as air temperature, snow fall, surface temperature, underground temperature, and temperature of freezing point are displayed on the graph. And the 3 statuses (warning, weather, road-surface status) at every hour are also displayed on the footing. The static image and each data numeric value of applicable time are on the rightmost edge.

(2) Static-Image Expansion screen (Fig. 5)

It is the screen which displays the magnified picture and the five above-mentioned data of that time.

Fig.3 Example of install of local station

3.4 The distinctive characteristics of a system

The following items are characteristics of this system.

(1) Able to check the power of remain Agents on the road and road conditions since we use buried type sensor.

(2) Able to pass exact circumstantial judgment by making stationary images and semi-dynamic images cooperate with a road meteorological data.

(3) Can expect improvement of forecast accuracy by cooperating this system with a weather forecast system.

(4) Easy to share the data with other systems since the general-purpose communication's protocol is used.

(5) The operation is easy with the simple screen structure.

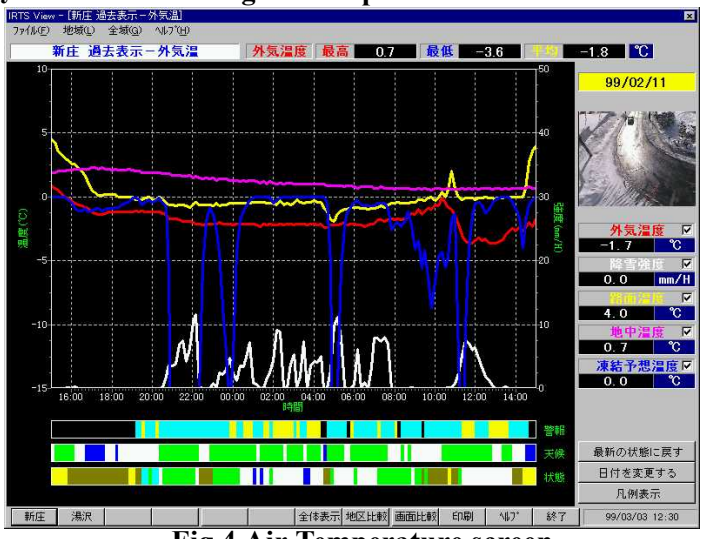

Fig.4 Air Temperature screen

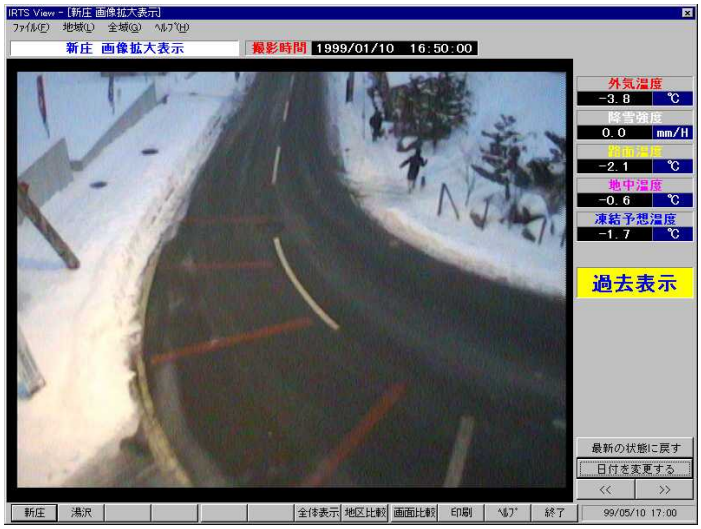

Fig.5 Static-Image Expansion screen

3.5 It is expectable effect with system introduction

Following four improvements are expectable by introducing this system.

(1) Securing the safety traffic in winter road.

(2) The reduction of an environmental influence and a sprinkle cost by the optimum sprinkling Agents.
(3) Improvement of working efficiency for sprinkling Agents.
(4) Accumulation of the logical and numerical data about a winter road management.

4. The Sample of this System Introduction

Now, this system is working in two cities, Sendai City (five sensors is installed) and Morioka City (six sensors is installed). Here we refer to the case in Morioka City in order to introduce the effect of this system.

4.1 Issues in Winter Road-surface Management in Morioka City

Morioka City is the location, which is shown in Fig.6.

Morioka City is located in almost same LAT with Madrid or Lisbon. The average Air-temperature in January is about -2 degrees C, Maximum about 7 degrees C, Minimum air-temperature about -11 degrees C and Precipitation about 50mm. There are about 280,000 populations.

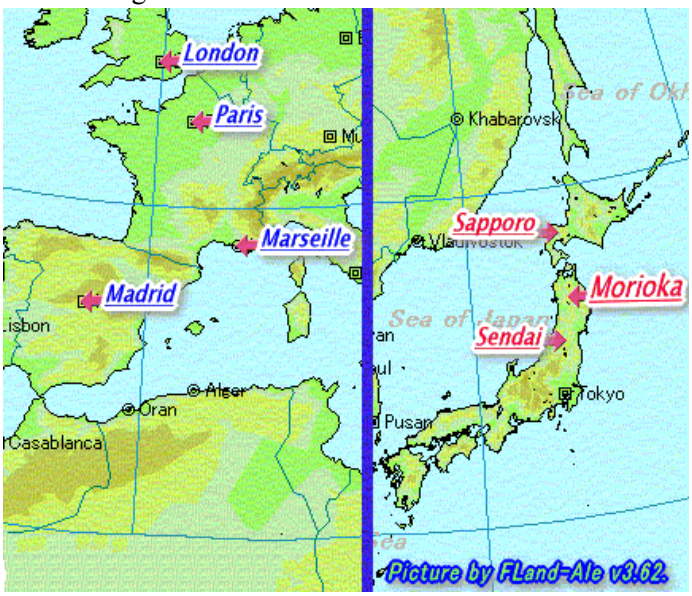

Fig.6 Morioka City is the location

The sprinkling Agents system has been strengthened since 1994 fiscal year, and it has endeavored to solve the problem of a breezed road-surface as much as possible. However, the sprinkling cost had increased and it occupied 40 percent of the total consignment cost by 1995. Furthermore, because of the demand that uses less non-chloride Agents with little influence on environment and structure, we needed to consider not only the reduction of the amount of Agents but also the quality of Agents today. Before this system installed, the problems are as below;

(1) Morioka City had carried out patrol in every morning for a detailed road management. However, it was impossible to patrol from all angles because of time limit.
(2) Partial patrol such as the identification of parts is made a complaint. Therefore, it was difficult to manage good road condition that changes every moment.
(3) The Morioka City office's staff had shifted to usual work after few rests from patrol activities early morning. Therefore, there was a problem in respect of the Morioka City office's staff's health management. It became important how to reduce the staff load without lowering quality of patrol work.

In order to solve the above problems, this system was introduced as the winter road management system which can link the winter road-surface monitoring system and the weather forecast system.

The concrete contents of the system are as below. The management area was divided into six areas, which change a weather characteristic. The local station of road-surface monitoring-system was installed in the characteristic spots in these divided management area. The main station was

installed in the Morioka City office. The sub station also was installed in the sprinkle consignment Company and the weather forecast business Company.

The local station introduction of the winter road-surface monitoring system to a management area was started from 1998 under the condition that the local station would install two every year and installed in a total of six places finally.

4.2 The effect of introduction of this system

4.2.1 The issue of quantity-validation

In order to check up the introduction of quantity-validation on this system, we have investigated the snow-removal related cost and the amount of the Agents used from 1995 to 2000. However, because of weather conditions changing every year and the changing of road span of control (a extension of snow-removal area and an point needed deicing/anti-freezing Agents) it had some trouble to make a comparison directly. Therefore, to evaluate this system induction effects in quantity, disturbance, we need to correct the data of weather surge.

4.2.2 Coefficient of Variation of the weather winter road-surface

In order to standardize the annual weather changes, we have introduced the winter road-surface weather coefficient of variation (Xyear) which evaluates the weather condition. Generally, statistical technique is used for evaluation of a weather changing. However, the new idea is needed to observe the road-surface of winter this time. For that reason, referring to the road surface sorting (Ref. 6), we have created the figure displaying the change of road-surface condition as we needed to know which weather condition is important of the winter road-surface.

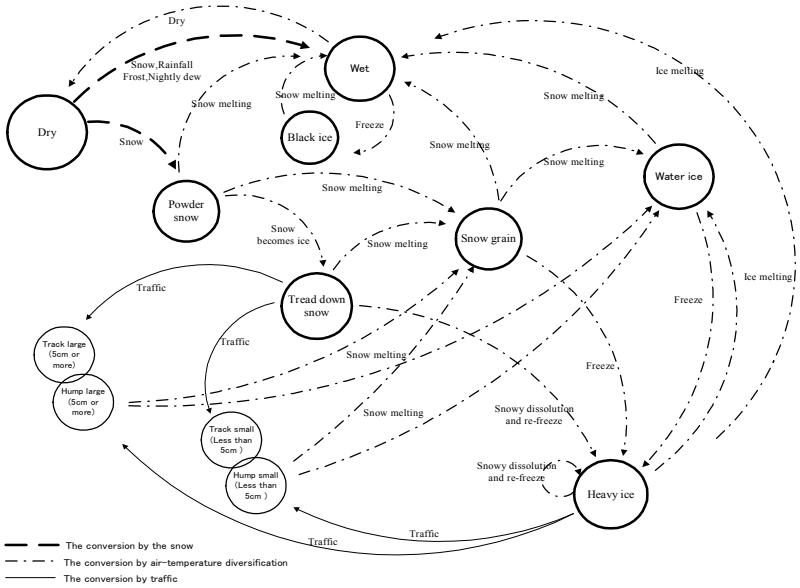

Fig.7 Figure displaying the change of road-surface condition

This drawing (Fig. 7) has expressed the road-surface condition with the circle. And the arrowhead, which connects a circle, expresses changes of state, such as snow coverage, a thaw, a freeze, and traffic volume. From this, we understood that air temperature conditions and snow-coverage conditions have influenced in great deal. At the same time, we found that repetition of dissolution and a re-freeze tend to form a dangerous road-surface.

Thus, we evaluated about the following three items as weather conditions, which affects a winter road-surface.

(1) **Air temperature conditions**: Calculate the number of the days that a road-surface may freeze

(2) **Snowfall conditions:** Calculate of snowfall and snow. The snowfall is referred to the road management criteria of Morioka City

(3) **Road-surface conditions:** The road-surface conditions by using an air temperature, the

compound condition of snowfall, and time conditions.

The evaluation standard of each weather condition of air temperatures, snow coverage, and road-surface was shown in Table.1. As to the meteorological data taken from management term data (December 1 to March 31 of next year) we picked up from the monthly report data of the Morioka Local Meteorological Observatories with many amounts of data base.

Table.1 Evaluation standard of each weather condition

Item		Conditions
Xtemp	a	Ave.-temperature is below zero.
	b	High-temperature is below zero.
	c	Low-tamperature is below zero.
Xsnow	a	There was snow coverage.
	b	There were 5 cm or more of snow coverage.
	c	There were 10 cm or more of snow coverage.
	d	Snow had lain.
Xroad	a	The precipitation had Low-temperature below zero.
	b	The snow coverage had 5 cm or more of High-temperature below zero.
	c	The snow coverage had High-temperature below zero.
	d	The snow coverage had High-temperature below zero. It continued on 2 day.
	e	The snow coverage had High-temperature below zero. It continued on 3 day.
	f	The snow coverage had High-temperature below zero. It continued on 4 day.
	g	The snow coverage had High-temperature below zero. It continued on 5 day.

After a daily meteorological data compare with each design condition, it suited with it, 1 and not suited, 0. Then, it totaled on each condition. Furthermore, aggregation dispensation is calculated and computed between each condition. A mathematical expression is shown below. This expression refers to Danish Winter Index (Ref. 7)

$$Xyear = \sum_{December}^{March} Xday$$

$$Xday = \sum_{a}^{c} Xtemp + \sum_{a}^{d} Xsnow + \sum_{a}^{g} Xroad \quad [Xday\ is\ 0\ to\ 14]$$

We drew the correlation graph between the daily amount of Agents and Xday in 1998 to verify the correlation between verified coefficient and the amount of sprinkle Agents. (Fig.8).

As to this graph, the Xday values 1 to 3 are flat. The reason why is that the value of Air temperature conditions (Xtemp) has influenced. When Xday reach three or more, it turns out that the relationship between Xday and Agents irrelevance turns into a proportionality relationship.

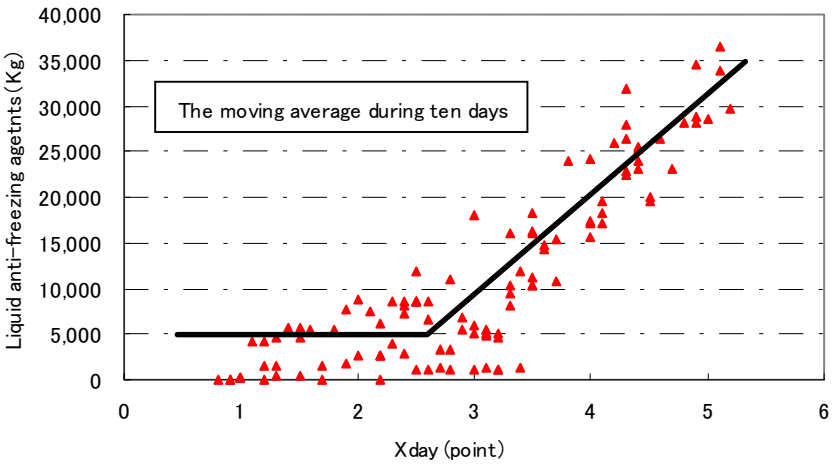

Fig.8 The evaluation standard of each weather condition

From this verification, it clears that there is correlation between Xday and the amount of sprinkle Agents and we can use Xday this as a value, which offsets a weather surge of the winter road management. And at the time, the variation percentage (VP), which shows the deviation from each year average, shall be used.

$$VP = Xyear / \overline{Xyear}$$

Xyear and VP of Morioka City from 1993 to 2000, which calculated through the method

mentioned above are shown in Table.2. Moreover, the winter road management (Agents sprinkle part) for every year is also shown collectively.

Table.2 Xyear and VP of Morioka City from 1993 to 2000

Year	Xyear				VP	The Road Span of Control
	Xtemp	Xsnow	Xroad	Total		Anti-freezing Agents Dispersion Parts
1993	185	115	46	**346**	**0.928**	
1994	188	132	60	**380**	**1.019**	
1995	189	153	65	**407**	**1.092**	352
1996	174	100	46	**320**	**0.858**	396
1997	183	126	71	**380**	**1.019**	426
1998	187	110	54	**351**	**0.942**	426
1999	176	112	44	**332**	**0.891**	422
2000	219	153	94	**466**	**1.250**	426
Ave.	183	121	55	**373**	**1.000**	408

4.2.3 The Result of evaluation

A consignment fee of sprinkle Agents and the amount of sprinkle Agents are evaluated as the numerical effects of this system. The evaluation was conducted through the method that revises the disturbance for every year Moreover, because the price of Agents is fluctuating every year, revision of the price of Agents was conducted on the basis of the 1998 fiscal year.

The concrete arithmetic means are as follows.

(1) Agents sprinkle cost =

Agents sprinkle cost / sprinkle part / VP

(Agents sprinkle expense =

Correction value of the Agents price rate)

(2) The amount of Agents use=

All amount of Agents use / sprinkle part / VP

The result of the evaluation of the quantity-appraisal of the effect of introduction was shown in Fig.9 and 10.

From Fig. 9 is showed transition of Agents sprinkle cost. It turns out that about 20% cost reduction had been achieved between 1998-2000 compared with 1995-1997 in which system was not installed yet. On the other side Fig.10 are showed the amount transition of the Agents use and it turns out that they could cut 25% of the amount of sprinkle Agents after the introduction of the system.

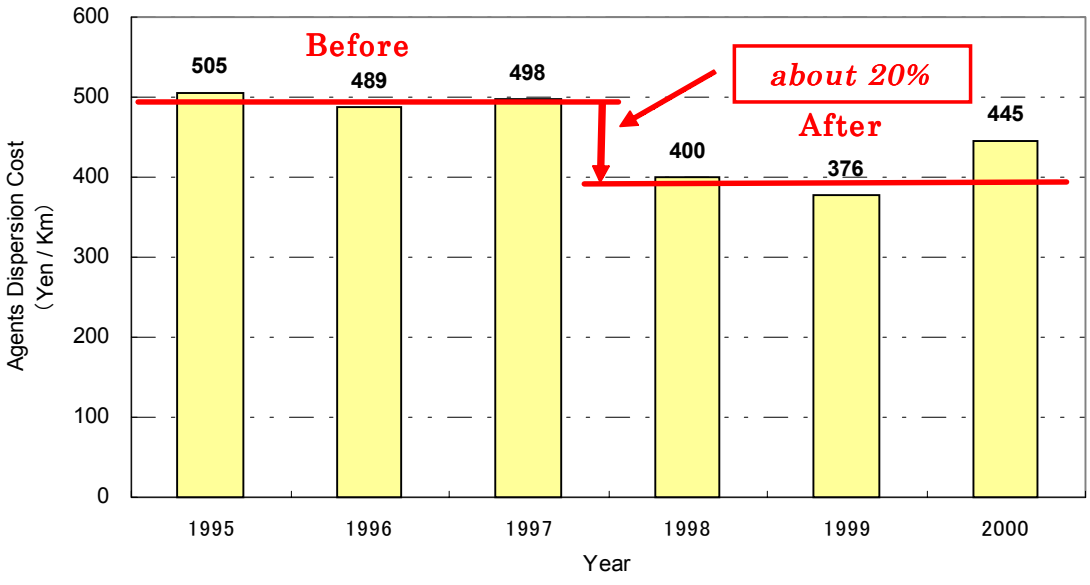

Fig.9 The amount transit of Agents dispersion cost

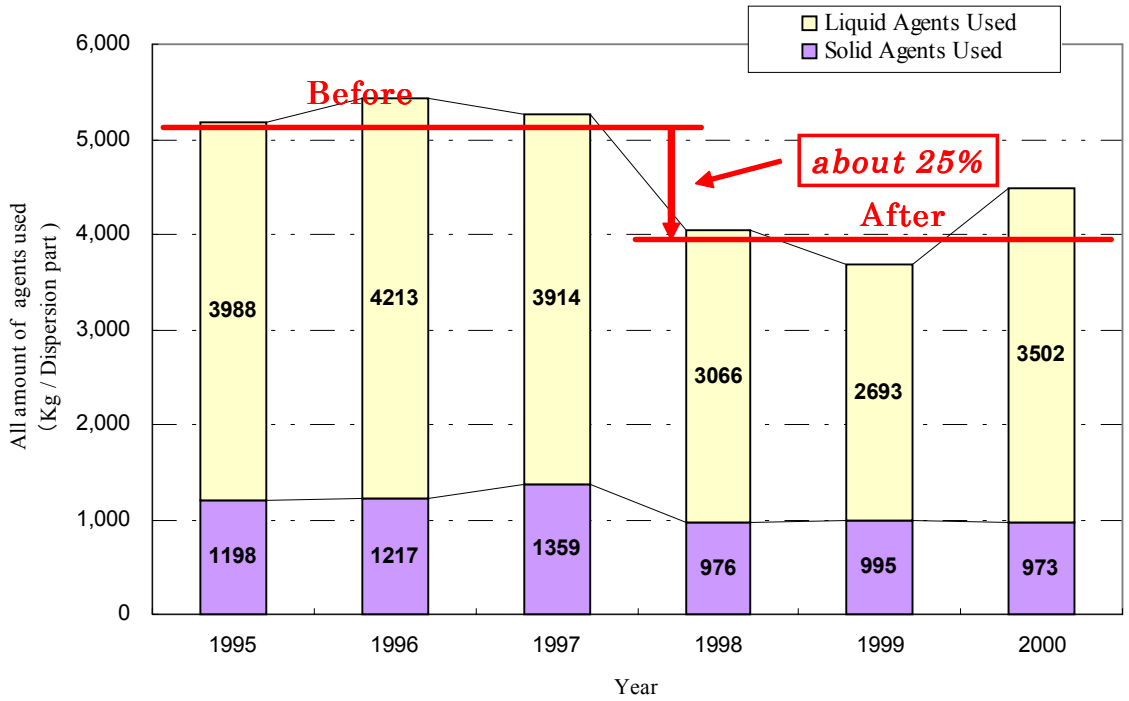

Fig.10 The amount transit of Agents used

4.2.4 Other Effects

Here we are going to mention other effect by introduction of this system in addition to the cut of sprinkle cost and the amount of the Agents use.

(1) Achievement of improvement of efficient snow-removal system.
(2) Retrenchment of expenditures, such as consignment and overtime pay, was realized.
(3) It is expected that the improvement of winter road management by accumulation of knowledge.

5. Conclusion

This system archived the big numerical success of 20% cut of the sprinkle cost and 25% cut of the amount of the Agents use in Morioka City. And the environmental influence by Agents use has also been reduced. Furthermore, we could also obtain big cost performance for the working management of Morioka City office and Agents carried out the road management.

From now on, while our company improves the road management accuracy by cooperation between Thermal Mapping and this system based on know-how obtained by this system development, we want to develop the new Agents with consideration to the environmental influence.

Acknowledgement

We are deeply grateful to related person (Morioka City, Sendai City, Sapporo City, etc) who cooperated with an investigation the system, the development, operation, and data analysis.

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