SNOW AND FREEZING CONTROL SYSTEM IN METROPOLITAN EXPRESSWAY

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Abstract: Snowfall is generally not a major problem in Tokyo Metropolitan Area. There are a few snowfalls in usual winter season and the average annual amount of snowfall is only several centimeters in Tokyo. However, when a heavy snowfall happens in Tokyo once per several years, harmful effects on the traffic are expected since the traffic volume in Tokyo is so large. In urban area it is important to take a quick countermeasure against snow in order to minimize the traffic malfunction while many snowmelt facilities and costly snow-removal machines are not allowed from economical reason. In this paper, the abstract of the snow control system in MEX is described. This includes a main policy, an emergency deployment system under snowing weather, utilization of the traffic control system with traffic surveillance monitors , a criteria for the road surface condition, a standard scattering amount of a deicing agent, and a combination of facilities. Examples of the snow damages and the countermeasures against snow in recent years are also introduced.

1. Introduction

The Metropolitan Expressway (MEX, a presently 264km toll expressway network in Tokyo) is a main artery in Tokyo Metropolitan area, responsible for the metropolitan traffic supporting the population of some twelve million, used by 1.16 million cars and some two million persons per day. MEX, with only some 13% of the total length of major roads in Tokyo, supports some 28% of the total amount of traffic and some 38% of the total amount of freight transportation, as a basic transportation facility in the metropolitan area. The current network of MEX is shown in Figure-1. Accordingly, as for countermeasures

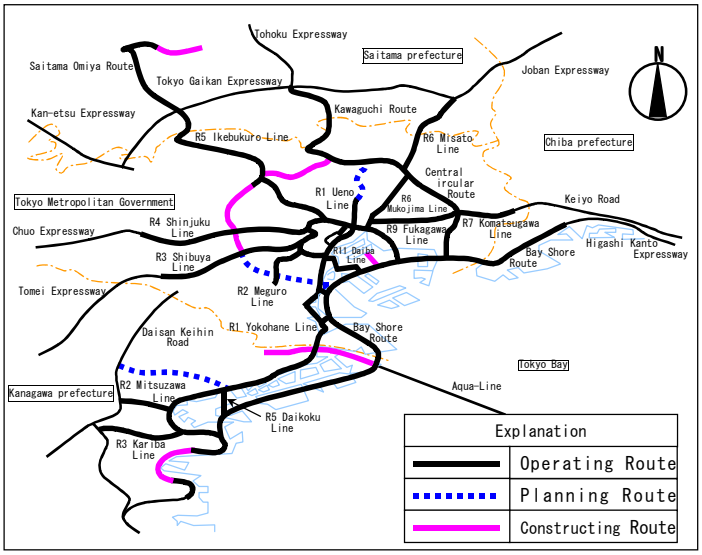

Figure-1 Network of Metropolitan Expressway

Against snow damage in MEX, more care should be taken on keeping traffic capability, compared with countermeasures generally reported in snow districts. Then, countermeasures against snow damage in MEX have a severe aspect different from those in snow districts.

The Tokyo Metropolitan Area had little trouble with snow in the past as it snowed only several times per year. Once traffic was stopped by heavy snow, however, it did serious damage to not only the metropolitan area but also its surrounding regions, due to the increase of the population and the amount of traffic in the metropolitan area. Hence, it is important to take countermeasures against snow damage in response to such conditions.

The first case of snow damage in MEX represented heavy snow on the 19th of January in 1984. When 26 centimeters of snow fell, which was the second deepest in the history of MEX at that time, efficient countermeasures couldn't be taken against snow damage only to stop traffic in MEX for four whole days. The role of MEX as a basic transportation facility was found so big because more than 20 years had passed since its operation started. That is, four-day closure of MEX made capability traffic come to a standstill, with a damaged-influence over neighboring areas, and it evoked a big response from people. The record of snowfall in Tokyo after the foundation of Metropolitan Expressway Public Corporation (MEPC) is shown in Table 1.

Since then, the consciousness of countermeasures against snow damage in MEPC has been raised to much higher level, and MEPC has made efforts to improve countermeasures against snow damage in urban roads. And the following points has been improved: introduction of more-efficient machines for removing and clearing of snow, countermeasures against freezing, forming personal readiness for countermeasures, responding quickly to traffic, using a large-scale control facility, and the like. Nevertheless, new problems have still emerged whenever it snowed heavily once in several years.

This paper shows the characteristics of snowfall in Tokyo and how countermeasures are taken and prepared against snow damage in MEX, and in addition, identifies and analyzes questions to raise our future's challenges.

Table 1: Frequency of heavy snowfall warnings in Tokyo

Order	Year	Snowfall (cm)	Order	Year	Snowfall (cm)
1	1969	33	6	1984	17
2	1994	27	6	1992	17
3	1984	26	8	1967	16
4	1969	21	8	1986	16
4	1978	21	10	1975	15

2. Characteristics of Snowfall in Tokyo

The Japanese-Islands is located between the Sea of Japan and the Pacific along the eastern coast of the Eurasian Continent, a biggest continent in the world. Accordingly, the Japanese climate is greatly influenced by the Continent and the Seas. Particularly, the winter weather in Tokyo located in the eastern part of the Japanese-Islands is strongly influenced by the following factors: the scale of dominant Siberian cold and high pressure, the location of lows and fronts affected by relatively warm climate in the sea, compared with that of the continent, and the degree of their development. That is to say, Siberian cold air absorbing much moisture over the Japan Sea often makes heavy snowfall in the Japan-Sea side of and the mountain ranges in Honsyu and brings a dry and clear sky in Tokyo. But once the winter pressure distribution of western high and eastern low is broken and moving south of cold airs becomes less powerful, low passes over the southern coast of Honsyu to bring a lot of snowfall in Tokyo and its vicinities. Table-2 shows the

frequency of heavy snow warnings in Tokyo by major cause for snowfall. In general, most of the heavy snow in Tokyo is brought by southern-coastal low, and in this case the amount of snowfall is large and its time long. When cold low passes, it may snow heavily with gust and thunder in a short time. In addition, snow brought by a convergence line or strong winter pressure distribution falls softly and suddenly and seldom stays.

Table 2: Frequency of heavy snowfall warnings in Tokyo(Statistical period: 1991-2000)

Pressure distribution	Southern-coastal low	Cold low	Convergence line	Strong atmospheric pattern of winter	Total
Frequency (times)	6	1	0	0	7

Note: In general, the heavy snow warning issues in Tokyo when five centimeters of snow fell for 24 hours.

Next, the characters of winter weather in Paris and New York are briefly introduced, and compared with that in Tokyo.

Paris located in the western end of the Eurasian Continent, opposed to Tokyo, and is covered with "West-coast oceanic climate". In the Northern Hemisphere, the sea temperature is generally high in the west coast of the continent due to the warm current, compared with that in the east coast. Warm air tends to enter in temperate regions in the west coast of the continent because of the disturbance of lows, and it often brings air exchange between the north and the south. Then the climate is warm there, compared with that of the same latitude of regions in the east coast of the continent. In addition, there is no common pressure distribution there under which cold air blows in from the continent, representative of Japan. Therefore, although the latitude of Paris is higher than that of Tokyo by some thirteen degrees, the temperature in Paris hovers on a little lower degrees than in Tokyo, the number of snow days in Paris is larger than in Tokyo but the precipitation there is less than here.

New York is located in the east coast of the continent like Tokyo. However, as the North American Continent is smaller than the Eurasian Continent, the temperature in that continent is not as low as in Siberia, and highs are rarely spawned. Then, in New York, lows pass easier than in Tokyo where lows pressed by cold air pass offshore, and the phenomenon of snowfall in New York occurs more frequently than in Tokyo. The average of the precipitation in winter is 1.3 times higher than in Tokyo, and the average number of snow days is 2.8 times larger. The latitude and longitude of observation points are shown in Table-3, and the monthly-average temperature, precipitation and the monthly-average number of snow days are shown in Figure-2.

Table 3: Observation points of Temperature & Precipitation and Number of Snow Days

Observation point	Latitude	Longitude
Tokyo	35'41" N	139'46" E
Paris	48'58" N	2'27" E
New York	40'46" N	73'54" W

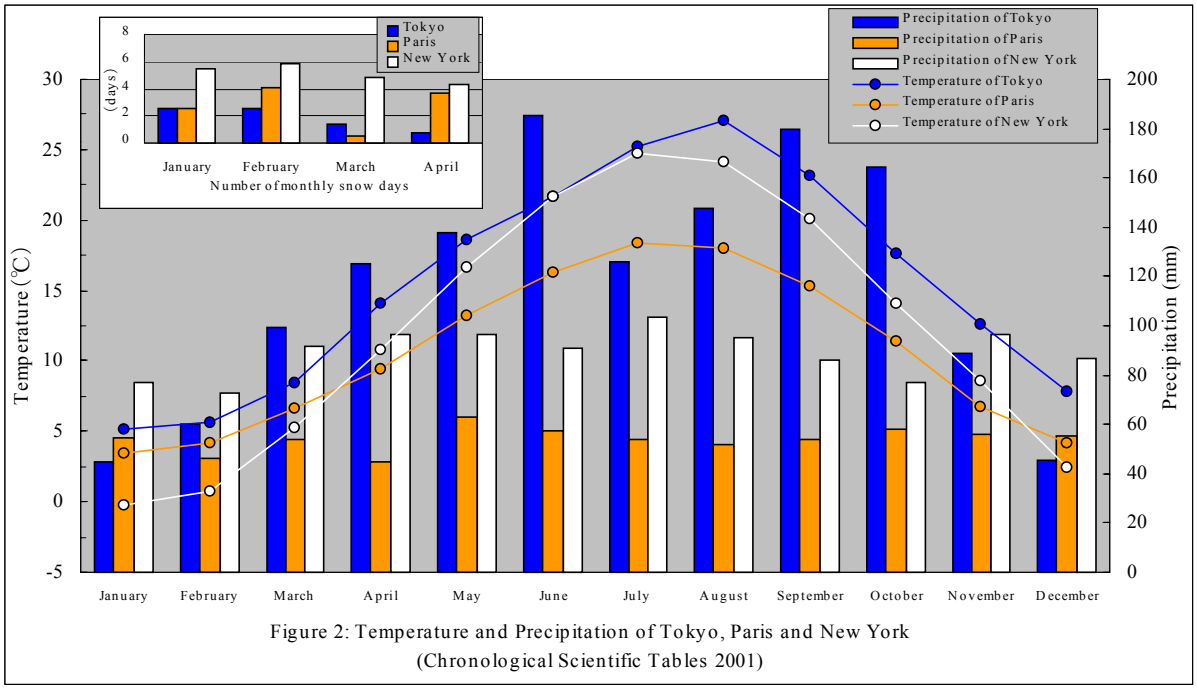

Figure 2: Temperature and Precipitation of Tokyo, Paris and New York
(Chronological Scientific Tables 2001)

3. Countermeasures against Snow Damage in Metropolitan Expressway

3.1 Problems with controlling countermeasures against snow damage

Since MEX is constructed by using urban space three-dimensionally, it has problems in countermeasures against snow damage as follows;

i) As the frequency of snowfall is low, it is not allowed to install snowmelt facilities and machines designed for snow removal permanently from the economical reason. Therefore, it is important to take rapid countermeasures whenever snow falls. Machines for civil works are used to remove snow, so labor efficiency is low.

ii) As 80% of the network of MEX consists of elevated bridges with many installed facilities, the solar radiation heat is low and geothermal snowmelt cannot be expected.

iii) As most of the routes, except Bay Shore Route and Central Circular Route, have narrow shoulders, once vehicles become incapable of traveling at the time of snowfall, they obstruct lanes and hinder work, so labor efficiency reduces greatly.

iv) As durable pavement against ruts is applied on MEX, the space of each durable aggregate is wide so that water on the road tends to seep into the pavement and stay there. As a result the surface of the road freezes easily at the time of snowfall.

v) When snow is removed, it should be take out of roads without splashing it out from the Expressway. So labor efficiency is low and long hours of work are required.

vi) It's hard to secure a dumping place of snow because there aren't many vacant lots in urban areas.

vii) Snow is removed in the following steps: first taking it out of the passing lane to the regular lane, and then piling it on the left shoulder. However, sometimes the work steps need to be changed owing to the alignment of the Expressway peculiar to urban areas.

From the above problems, problems of the number iii), v) and vi) are peculiar to urban areas. Above all, as for problem number i), the system for taking countermeasures against snow

damage is formed based on weather information. Hence its efficiency depends on the accuracy of the weather information.

3.2 Systems for taking countermeasures against freezing and steps to remove and clear snow

3.2.1 Systems for taking countermeasures against snow damage: The period from December 1 to March 31 is set for taking countermeasures against snow damage every year in order to maintain regular capabilities of MEX in winter season. Systems are listed shown as follows:

i) Initial system: When road freezing or snowfall is expected based on weather information, etc., patrols are carried out to confirm road conditions including road temperature, dry or wet condition, etc. (this is to be repeated in the following), as necessary.

ii) First system: When snowfall or road freezing in controlled areas and its vicinities is reported, or road freezing is expected, chemicals' scattering is carried out based on each road condition.

iii) Second system: When snow removal or chemicals' scattering needs to be carried out according to the condition of road freezing, snowfall or depth of snow, or when heavy snow advisory is issued, the system is reinforced according to weather forecasts and road condition.

When heavy snow warning is issued, the above system is reinforced to stand prepared against urgency or emergency. Criteria of road conditions are shown in Table 4.

Table 4: Criteria of Road Conditions

No.	Road conditions	Criteria
1	No feeling of moisture when one touches at the road. No water exists in aggregate.	Road condition 1
2	Some feeling of moisture when one touches at the road, but one need not wipe one's hand.	Road condition 2
3	The hand becomes wet when one touches at the road. No water is running on the road surface , but water exists in aggregate. The running car doesn't spray.	Road condition 3
4	Water exists on the road surface and the running car sprays.	Road condition 4
5	The road is in a sherbet condition.	Road condition 5
6	It's in danger as the road surface is frozen.	Road condition 6
7	There is a snowfall on the road surface.	Road condition 7
8	There is a snowfall on the edge of the road surface. The level of road condition is any of 1 to 6.	There is a snowfall on the edge of the road surface. The level of road condition is any of 1 to 6.

3.2.2 Steps against road freezing: On MEX, calcium chloride is adopted from chemicals commonly used for taking countermeasures against road freezing, such as calcium chloride, sodium chloride, magnesium chloride and urea, because of its good keeping, solubility, continuity, quick-acting nature, and the like. $30g/m^2$ of calcium chloride is scattered on the road when water on the surface freezes at -5℃ (the concentration is about 8%). In addition, it is recommended to carry out scattering of calcium chloride in the following steps:

i) Scatter calcium chloride initially when snow starts to fall, and scatter it to prevent freezing after removing snow.

ii) Scatter calcium chloride to prevent freezing after it stops raining.

iii) Scatter calcium chloride to prevent freezing after removing snow.

iv) Scatter calcium chloride to prevent freezing road surface from melted snow on the medial strip and the shoulder.

Besides, when the temperature of road surface is under –5℃, the amount of scattered calcium chloride increases by 10g/m^2.

3.2.3 Snow-removal steps: In principle, snow removal is carried out in the following steps;
i) In the main line, it should be done on the two lanes simultaneously. And it is removed with graders, etc. by the working party. As regular vehicles follow a working car, a beacon car is made to accompany the working car to ensure safety behind it.
ii) Snow is collected and put on the left side of the road to secure two lanes in general.
iii) Snow removal is carried out with care not to leave snow on the road as much as possible.
iv) During snow removal, the working speed is properly decided according to the condition of site so as not to splashed out snow from MEX and not to obstruct the traffic of ordinary roads.
v) Snow removal is repeated so as not to exceed the snow depth of 5cm generally.
vi) The primary aim of snow removal is to secure lanes in a short time as soon as possible.
vii) Snow removal is repeated on each ramp off and on. As it takes long time to remove snow on all ramps, priorities are set for removing snow on the ramp.

3.2.4 Steps to dispose of snow: To clear snow, snow is carried away as soon as possible after snow removal, in principle based on the following items;
i) In clearing snow, the priority should be given to the place where snow piled and collected on the shoulder makes the width of the road narrow partly, or where water running on the road after snow is melted on the shoulder on the higher end of the cross section of the road, is lilkely to freeze again.
ii) Clearing snow is done so as to avoid traffic jam where possible.
iii) When the snow left after snow clearing is likely to freeze again, countermeasures including scattering chemicals, etc. are taken.

In 1996, MEPC has 18 snow dumping places and some 78,000m^2 areas in total, including lands and facilities controlled by MEPC in the area of Tokyo and Kanagawa (e.g. space under the elevated bridge or on the tunnel).

3.3 Monitoring and Control System of Traffic

3.3.1 Using surveillance monitors designed for all routes of Metropolitan Expressway: MEPC checks the condition of traffic on the road through the traffic surveillance monitors installed in almost all routes on MEX. When countermeasures are taken against snow damage, the Corporation checks road conditions as well as the progress of snow removal or clearing at each route and each point through surveillance monitors visually to change the deployment of the working party as necessary. The half view of the traffic surveillance monitor is shown in Figure-3.

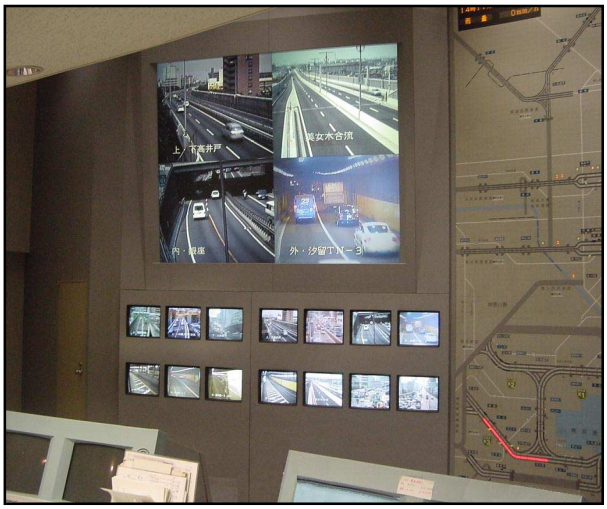

Figure 3: Traffic Control Monitor

3.3.2 Traffic control linked with countermeasures against snow damage: The Traffic surveillance monitors mentioned above are basically in charge of the traffic control section. When countermeasures are taken against snow damage, the link between the maintenance section and the traffic control section is formed. When snow is removed or cleared while opening the routes, the traffic control section is responsible for checking that there are no points of hindrance to traffic and deciding whether routes can be opened or not. When the routes of Expressway are closed, not only the maintenance section but also the traffic control section check the road condition to make a decision opening the routes again or not and the progress of snow removal or clearing visually. This check is made by first, seeing the road conditions through the surveillance monitors mentioned above, and lastly traffic patrol parties check them visually.

3.4 Installing of Snowmelt Facilities

At the site where the slope is very steep and snow should be quickly eliminated at the time of snowfall for the safety, the snowmelt facilities are installed. At some part of the ramp, junction, the entrance and the exit of the parking lot.

Table 5: Sites of snowmelt installation

Snowmelt method	Route	Sites of snowmelt installation
Water-heating	Inner Circular Route	On the ramp of Kasumigaseki
	Inner Circular Route	At the tollgate of Takaramachi
	Route No.1 Haneda Line	At the entrance and exit of the parking lot on the climbing lane of Heiwajima
	Route No.11 Daiba Line	At the entrance and exit of the parking lot of Shibaura
	Bay Shore Route	Ooi JCT
Electric	Route No.2 Meguro Line	On the ramp of Togoshi and Ebara
	Route No.4 Shinjuku Line	On the ramp of Shinjuku

There are two types of the snow melt facilities : the water-heating and the electric-heating. In the water-heating method tap water is warmed up to the given temperature with gas boiler and splashed over the road from a nozzle to melt snow. The temperature of warm water should be set at about 15℃, because the steam, produced by splashing high-temperature water, gives the harmful effect on running cars.

The electric heating method (road-heating) prevents snow from heaping up with the help of heat of heating wires embedded in the surface of the road. The list of the sites of snowmelt installation is shown in Table-5.

4. Cases of countermeasures against snow damage

In this section, the cleaning and removal system of snowfall experienced from 26th to 29th of January in 2001 (snowfall: 20 cm in depth), the route securing process by utilizing the system, countermeasures against freezing and challenges in the future are described.

4.1 Overview of Atmospheric Conditions around Japan and Snowfall

On the 26th of January 2001, the pressure distribution around Japan showed that the atmospheric low was spawned at the front located offshore of the northwest of Kyushu while the front located at the south coast. Then the low moved to east-northeast, and at 6:00 of 27th, it was on the sea south east from Kii Peninsula. Almost at the same time the low moved along the south coast of Japan, and a cold high was moved to Okhotsk from Siberia.

The weather forecast at 1:00 of 27th announced that snow would start to fall before dawn and continue to fall till the morning of the 27th, then it would change to rain during the day, as

relatively warm atmosphere would come in around the center of the low. The weather forecast at 5:00 announced that snowfall would be 20 to 40 cm in depth in the northern areas along mountains in Kanto, however in the plain field in the south of Kanto, it would be 2 to 3 cm in depth, and rain would be mixed with snow, and there was no correction of forecast. The thrown out cold high decreased the speed of the low, letting cold air flown into the lower part of atmosphere, keeping the snow associated with low falling without changing to rain even in the south of Kanto.

As for advisories and warnings on snowfall, a heavy snowfall advisory forecasting a snowfall of 5 cm or more in depth was announced at 8:00 on 27th and a heavy snowfall advisory forecasting a snowfall of 20 cm or more in depth was announced between 10:00 to 12:00. Snowfall changed to sleet from 17:30 or so, and the advisories were cancelled at 18:10. Then sleet changed to rain, however, snowfall reached to 6 cm in depth by 9:00 since it started snowing from 4:00. Snow fell heavily between 15:00 to 21:00, and the snowfall reached to 14 cm in depth, thus total snowfall reached to 20 cm in depth since start of snowing.

4.2 System for Removing and Cleaning Snow, and Conditions for Securing Routes

The system for removing and cleaning snow and the conditions for securing routes at the time in the Kanagawa area located to the south of Tokyo are as shown below.

At 21:00 of the 26th, the Control Department of Kanagawa got fully prepared against snow damage, and started patrolling at 2:25 of the 27th. It started snowing from 4:10 or so. Then the calcium chloride scattering parties on standby started their actions, and completed scattering of the specified amount of calcium chloride on all the routes at 8:15, while entrances into the routes were closed and vehicles were forcibly cleared from the lanes.

However, considering the accidents caused by slipping due to snowfall before, all the routes of Metropolitan Expressway in Kanagawa area were closed at 9:14 of the 27th. Then from 10:50, snow removal and cleaning started at all the routes in Kanagawa area. The initial system for removing and cleaning snow was shown in Figure-4. The work didn't make progress as expected since the amount of snowfall were increasing, and the working party was reinforced gradually to open the routes with two traffic lanes secured. However, the snowfall was too much and snow changed to sleet or rain, then the snow covering the roads froze, making it difficult to remove and clear snow, and finally requiring much labor and time. To take all the possible measures to ensure safety of traffic, a requirement that "not a slight snow should be left on the two traffic lanes before opening any route to traffic" was set. Thus, the working policy was changed so that snow removal and cleaning were intensively done on the roads determined to have higher priorities, and the closed routes were to open to traffic one by one. Therefore, final opening of the controlled routes was made at 17:30 of the 29th, which was 55.5 hours (about 2.5 days) after start of snowing.

4.3 Further Countermeasures against Freezing and Challenges

As described above, MEX owns the manual of countermeasures against snow damage and the facilities. In such a case where substantial snow fell in a short time, importance of the operation in accordance with the forecasted amount of snowfall and applicable system was emphasized again. Namely, in this case, the Metropolitan Expressway was closed in Kanagawa area for two and half days, which were resulted from the following factors.

i) Enhancement of countermeasure system against snow damage was delayed due to unexpected massive and continuous snowfall, which significantly exceeded the amount of snowfall announced

in the weather information. (It was so difficult to correctly forecast the slight difference between the pressure distribution causing this much of snowfall and a general pressure distribution in winter, as well as variation of it.)

ii) During this winter, accidents caused by slipping due to snowfall occurred before, and vehicles were shut out at an early stage, and thus snow cleaning conditions became stricter.

And the following items are found to be important: The weather and snowfall forecast, the establishment of the system according to the snowfall forecast, the establishment of a support system when snowfall exceeds the forecast or continues falling for a longer time, the recognition of the route conditions in details, and the thorough acquaintance of referential communication channels. Especially the selection of routes where traffic should be secured and where snowfall is to be cleaned and removed first, and preparation of machines and manpower to be arranged and assigned in accordance with the amount of snowfall are important. Naturally, this arrangement and assignment includes the cost for securing an extra system for removing and cleaning snow as well as the documentation of specifications on the timing when the system starts its actions.

Taking a lesson from this failure in countermeasures against snow damage, MEPC decided to improve the following two points.

i) Considering to provide an efficient countermeasures against heavy-snow damage, manpower system is to be enhanced.

ii) To further reduce accidents caused by slipping while snowing, improvement in countermeasures against freezing is to be studied by using sodium chloride liquid on a trial base instead of calcium chloride.

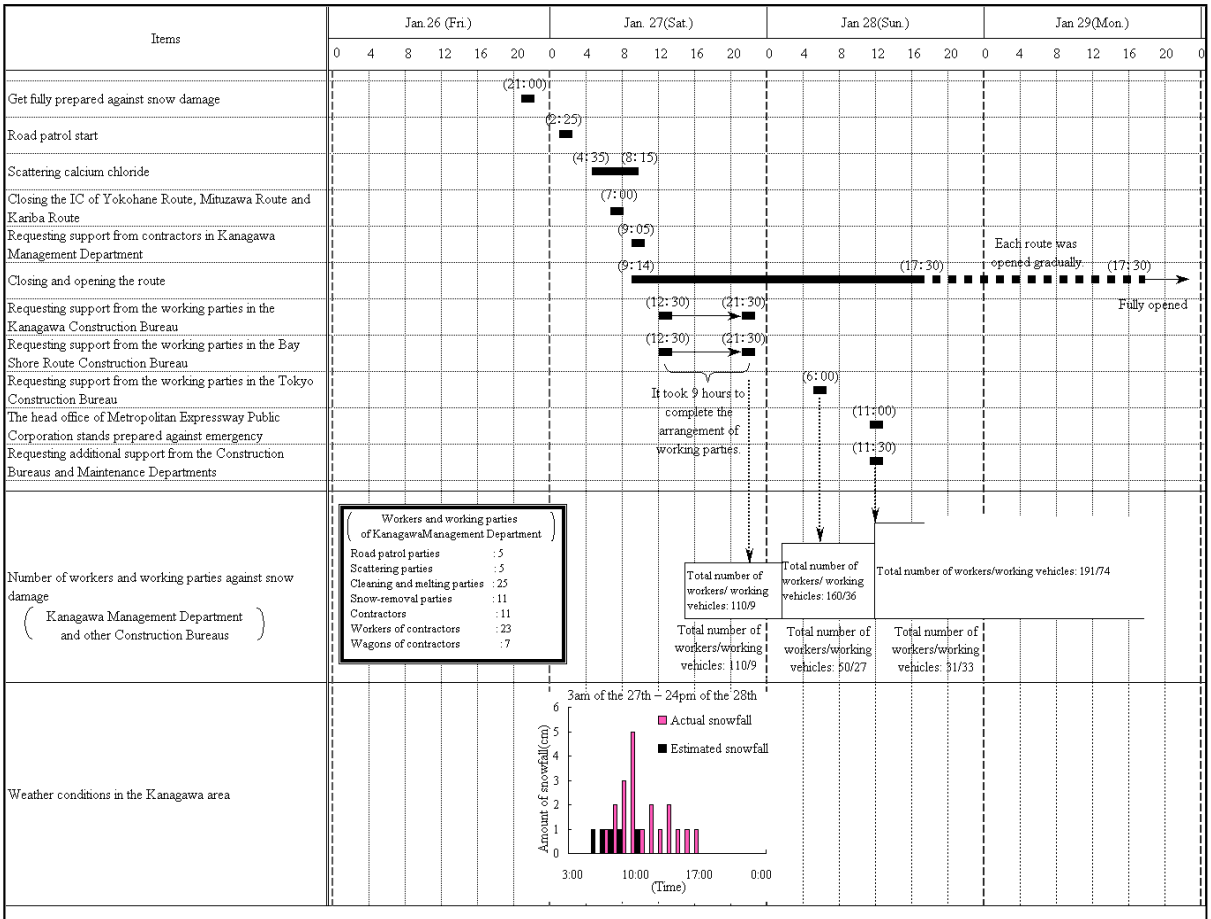

Figure 4: Countermeasures against snow damage taken from Jan. 26 to 29 in 2001

5. Conclusion

Considering the overview of MEX, systems for countermeasures against snow damage, steps and facilities, and cases of countermeasures against snow damage described above, the countermeasures against snow damage taken by MEX are summarized as follows;

i) Owing to the weather characteristics and economy, it is hard to secure countermeasure facilities against snow damage as well as equipment in the metropolitan area. Accordingly, it is essential to utilize weather information, and the accuracy of weather forecast and decision on whether the system for countermeasures against snow damage should be built up based on the forecast or not, affect the efficiency of actions against snow damage greatly. Especially, in building up a system for countermeasures against snow damage while snowing, throwing in the sufficient working parties in advance is important, based on the careful judgment on when it stops snowing is required.

ii) In the countermeasures against snow damage in the metropolitan area, there are many problems peculiar to urban areas sometimes deteriorating the labor efficiency. Taking such problems into account, it is a critical issue to provide education and training for expert party carrying out countermeasures in the urban area smoothly.

iii) The judgment about closing the Expressway is affected greatly by slipping accidents while it is snowing. This type of closing has a great influence on snow cleaning. Securing traffic safety is another important issue, and countermeasures against freezing should be studied in the future as an important issue in taking countermeasures against snow damage.

iv) For the places where snow removal and/or cleaning is difficult, efforts should be made for improvement of snow removal and clearing efficiency by increasing snow melting equipment or using some other means.