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Trains for tomorrow's travellers

High-speed train operation in winter climate

by

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PREFACE AND ACKNOWLEDGEMENTS

This is a study of the winter challenges regarding high-speed passenger train services in the European Nordic region. The investigation has been performed within the Swedish Transport Administration's (Trafikverket) research project "Gröna Tåget" (Eng: "Green Train").

In 2006 a winter report 'High-Speed Train Operation in Winter Climate' was presented as a part of the research and development programme "Gröna Tåget". That study was concentrated to the Nordic countries regarding the interviews. In addition a literature research brought up some high-speed winter solutions from other countries, mainly Japan.

As the gathered information was mainly from Norway, Sweden and Finland, a second study was proposed with the aim to include knowledge of very high speed operation which nowadays is common in train operation in many central and southern European countries. The new study was to include train operation far above 200 km/h.

The winter 2009 – 2010 was harsh, also in many central European countries and resulted in a number of winter-related operational problems. Governments in some countries and organisations, such as the UIC, have thereafter started investigations to find out what to do to reduce the problems in the future.

Many of the experiences in this report are from the winter 2009 – 2010. Some examples from Sweden are also given from the winter 2010 – 2011 that started in the same way with a long period of cold weather and a lot of snow as the year before. The big difference from previous winter was that snowfall and coldness, resulting in operational problems, started around a month earlier, mid – November in the Stockholm area.

The railway networks are in very many aspects combined regarding high-speed operation and operation of normal passenger and freight trains in lower speeds. That is why the high-speed trains most often are affected by the normal operation and vice versa. Some of the related experiences in this report primarily come from slower trains or even shunting movements. The reason is that they are a part of the railway system and in this case affects the entire railway operation.

The outcome of this investigation has been much dependent on the interviewed persons and their shared experiences. The persons included have different backgrounds but act in the railway sector. All interview persons have been very helpful and made contributions from different perspectives that have been of great value for the work.

I would like to thank all interviewed persons who through their participation have made this study possible. Also a special thank to the Swedish Transport Administration for financially supporting this study.

The previous report from 2006 has been the base for this extended report. I want to thank the co-writer of that report, Mattias Jenstav, for his good cooperation and contribution. Finally I thank Professor Evert Andersson at the Royal Institute of Technology (KTH) for his comments and helpfulness during the work to finalize this report. Nevertheless, any errors in this report are my own.

If nothing else is stated, the photos are copied from the author's collection.

Sundbyberg, September 2011
Lennart Kloow

ABSTRACT

This study is a part of “Gröna Tåget” (Eng: “Green Train”) research and development programme that is preparing for new high-speed trains in Sweden. The purpose of this study is to:

- Strengthen the ability to design the next generation high-speed passenger trains and infrastructure in Sweden.
- Influence the all-European standardisation of rolling stock and infrastructure.

During winters the train services in European Nordic countries – in one way or another and to various extents – are struck by constantly recurring problems related to snow, ice and coldness. If a winter is harsh and the circumstances are unfavourable the problems that arise can result in severe consequences for train operations and economy. That is why there has been a need for a project that gathers existing winter experiences and knowledge from a Nordic perspective, something a first investigation tried to fill and this extended edition adds further aspects to.

The main purpose of this investigation is to compile the knowledge and experiences regarding the high-speed passenger services in winter climate – the affects of snow, ice and coldness concerning both infrastructure and rolling stock. In order to fulfil this aim both a literature study and qualitative research interviews have been carried out with representatives of the European railway sector. From a Scandinavian point of view studies of this kind are of importance as most suppliers of rolling stock and railway equipment are concentrated to countries where the climatic conditions are different from the Nordic.

In Scandinavia the train services are expected to be unaffected during a fairly long winter time, except in the most severe situations. This results in higher requirements as regards design, operation and maintenance. This investigation looks into these demands from both a rolling stock and an infrastructure perspective for the Scandinavian high-speed services.

In the study all reported problems, as well as proposed measures against the problems, have been listed. The report forms a summary and checklist of winter problems, more or less irrespective of speed. Based on the list, the problems judged to increase at higher speeds have been pointed out in specific.

From this investigation the overall conclusion is that winter is unfortunately not an issue of high priority the year around. This conclusion can amongst others be drawn from the too often acute and short-term solutions and measures applied when the problems arise. The reason for this is often a “short memory”. After a number of mild winters with very few winter related problems, the responsible persons within the railway sector tends to forget which necessary preparations that have to be made and how to reduce the negative impact of a long and cold winter on the railway operation.

The study identifies that:

- There are still unsolved winter problems such as difficulties with switches, brakes, running dynamics etc.
- There is a lack of experiences and knowledge of high-speed operation (far above 200 km/h) in winter climate.
- The operational problems often increase with the duration of the winter period, i.e. the length of a period with temperatures below 0 °C, and the persistence to manage the rail operation is low.
- Many problems are more or less independent of the train speeds; others are expected to increase when the speeds of the trains are increased.

This study has shown that the high-speed winter problems (200 km/h and above) and the very high speed winter problems (250 km/h and above) are very similar although the following differences have been found:

1. The current collection, i.e. the system pantograph–catenary, is speed-dependent. Coldness or ice on the contact wire or on the pantograph’s arm or head degenerate the behaviour of the system more with increasing speed.
2. Every speed reduction or unplanned stop for a high-speed train gives a greater relative time loss than would be the case for a slower train. This indicates that trains for very high speed

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shall run on separate lines all year round to reduce the risk of them being stopped or delayed by freight trains or shunting movements.

3. Brake troubles and reduced braking effort will give significantly longer braking distances at very high speed.
4. High-speed tracks normally consist of improved infrastructure with a well drained ground and therefore the problems with frost in the ground are rather rare. When trains run at very high speeds, just small track alignment faults will create big forces. The running properties are affected and normally get worse with increased speed. The track movements will worsen the ride quality, increase the track forces and in worst cases, although unlikely, cause a derailment.
5. Snow packing in railway cuttings, especially packed on just one side, or avalanches over the line produce derailment risks to all trains. The effects will however be bigger the faster the trains run, the lighter the trains are and the less efficient the front snow ploughs are.

Further studies ought to focus on:

- Standardisation, authority requirements and verification of rolling stock and infrastructure needs to be looked into. There is a European standardisation work going on – CEN/TC 256 “Environmental Conditions” for railway applications regarding design and test of rolling stock under severe conditions.
- The recommendations for management of high-speed train operations in winter conditions must be improved. Especially they need to focus on managing operation during longer periods of coldness and snowfall.

The improvement also includes the co-operation between all the involved parties in the rail operation.

- To implement technical improvements must be an on-going process, both regarding the vehicles but also regarding the infrastructure and its snow clearing.

DEFINITIONS AND EXPLANATIONS

This study assumes the following definitions in alphabetic order:

Ballast pick-up	Macadam stones that are lifted from the ballast as a consequence of train passage.
DMU or EMU	Diesel or electric multiple unit.
Green Train	Swedish “Gröna Tåget” research and development programme which prepares for high-speed trains in Sweden and the Nordic countries.
Gröna Tåget	See Green Train
High speed	Speeds from 200 km/h and above.
High speed dependent winter problem	A winter problem that either: <ul style="list-style-type: none">• gets worse with the increase of speed,• is only found in high speed train services, or• causes increased problems to high speed train services e.g. speed restrictions.
Snow smoke	Dry snow that whirls around a running train.
UIC	International Union of Railways
Very high speed	Speeds from 250 km/h and above.
Winter problem	A problem regarding rolling stock, infrastructure, operation or maintenance that is due to winter.

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1 INTRODUCTION

1.1 BACKGROUND

This study is part of the R&D programme of “Gröna Tåget” (Eng: “Green Train”) that, as regards winter aspects, aims to:

- Strengthen the ability to design the next generation high-speed passenger trains and infrastructure in Sweden.
- Influence the all-European standardisation of rolling stock and infrastructure.

During winters the train services in European Nordic countries – in one way or another and to various extents – are struck by constantly recurring problems related to snow, ice and coldness. If a winter is harsh and the circumstances are unfavourable the problems that arise can result in severe consequences for train operations and economy. That is why there has been a need for a project that gathers existing winter experiences and knowledge from a Nordic perspective, something a first investigation tried to fill and this extended edition adds further aspects to.

The main purpose of this investigation is to compile the knowledge and experiences regarding the high-speed passenger services in winter climate – the affects of snow, ice and coldness concerning both infrastructure and rolling stock. In order to fulfil this aim both a literature study and qualitative research interviews have been carried out with representatives of the European railway sector. From a Scandinavian point of view studies of this kind are of importance as most suppliers of rolling stock and railway equipment are concentrated to countries where the climatic conditions are different from the Nordic.

In Scandinavia the train services are expected to be unaffected during a fairly long winter time, except in the most severe situations. This results in higher requirements as regards design, operation and maintenance. This investigation looks into these demands from both a rolling stock and an infrastructure perspective for the Scandinavian high-speed services.

1.2 PURPOSE AND QUESTIONS AT ISSUE

The general aim of this study is to collect and compile knowledge and experiences concerning passenger train services in winter climate, with the primarily interest in winter experiences from systems operated at high speeds. With this purpose and with aspects on rolling stock, infrastructure, operation and maintenance the investigation focuses on following critical issues:

- The worst winter scenario from a weather point of view.
- The most common and the worst winter problems.
- Winter problems getting worse with the increase of speed.
- The difference between high-speed train services and conventional passenger services during winter.
- The solutions applied – both successful and unsuccessful.
- Areas and solutions that ought to be examined or further investigated.

Together this is believed to give a collected picture of winter high-speed train services in Scandinavia including problems and possibly also solutions.

1.3 METHOD

The investigation has been performed with a literature study at first and a following qualitative interview survey. Throughout the literature study the problem area got further defined and a basis for the interviews was developed. A great number of interviews have been held with representatives from different parties within the European railway sector.

In the study all reported problems, as well as proposed measures against the problems, have been listed. The report forms a summary and checklist of winter problems, more or less irrespective of speed. Based on the list, the problems judged to increase at higher speeds have been pointed out in specific.

1.4 DELIMITATIONS

The following delimitations have been made throughout in this study:

- Neither freight trains nor diesel vehicles are included, although the impact on high-speed trains from slower trains in combined operation is mentioned where appropriate.
- Little consideration is taken to older rolling stock and well known measures – applied designs and techniques etc. – taken against winter. Focus of attention is on modern rolling stock.

On the other hand it has been noticed that older equipment often is more reliable in the wintertime and less sensitive to snow, ice and coldness. There must be something to learn from that.

- The efficiency, cost and possibility to implement the presented measures against winter problems have not been evaluated.

1.5 VERY HIGH SPEED ISSUES OF SIGNIFICANT IMPORTANCE

Out of all the problem areas that this study discusses, some winter issues are considered to be of significant importance from a very high speed perspective. These are winter problems that are expected to get worse with the increase of speed. They are to be found in the following areas:

- Running dynamics, Chapter 2.3.4 and Frost in the ground, Chapter 3.3.4.
- Disc brakes, Chapter 2.4.1.
- Pantograph, Chapter 2.9.
- Snow clearing of the lines, Chapter 3.3.1.
- Platform tracks, Chapter 3.5.2.
- Ballast pick-up, Chapter 3.7.

2 ROLLING STOCK

The winter climate conditions require thorough considerations on the various rolling stock design aspects. For instance, all equipment must be very robust in order to cope with the large ice build-ups that can weigh up to several hundred kilograms. This concerns for instance cables, pipes and other more sensitive equipment that is exposed to snow, melting water etc.

In the sections below identified rolling stock high-speed dependent winter problems are described. The first of the following sections deals with the worst climate conditions from a rolling stock perspective. Subsequently, problems related to specific rolling stock areas are discussed.

2.1 WORST WEATHER CONDITION

The countries studied have different climate conditions that make it hard to come to a general conclusion concerning the worst weather condition for rolling stock. The combinations of snow, temperature, wind etc make the conditions differ from one region to another. During a run a train may be subject to varying climate conditions, from coldness and dry snow to temperatures above zero centigrade. Furthermore, the various rolling stock designs react different to the various kinds of weather and are in some situations more sensitive than others.

Regarding what kind of weather that causes most problems from a rolling stock perspective, two different scenarios have been pointed out as particularly unfavourable. The first one is the occurrence of dry snow. This type of snow is light and consists of very fine particles that whirls around the train while in motion, as seen in Figure 1, and easily cling to the train. Dry snow builds up in areas such as the bogie, pushes inside the vehicle through e.g. air intakes and also affects disc brakes.



Figure 1. Snow smoke from the Swedish X2 tilting trainset. Although the track seems more or less free from snow, the train is surrounded by a cloud of snow.¹

The other harsh weather condition regards temperature changes – the crossing of the point zero degrees Celsius – which can be most devastating when it concerns ice accretion on the vehicles. Ice can build up on trains as the train borne snow melts and then freezes. This procedure takes place as a train carrying snow enters a warmer region or when a train has stopped and the generated heat from e.g. the brakes cause the snow to melt. The problems with ice then occur as the train again faces cold surrounding with degrees below zero. In Figure 2 there is an example of a bogie covered with ice.

¹ Photo from report 'High-Speed Train Operation in Winter Climate' (2006)



Figure 2. An example of a bogie with adhering ice, a German class VT 612.²

The different temperatures and air humidity affect the shape of ice and snow crystals. The common ice crystal has a flat six armed structure as in solid ice. Especially around $-15\text{ }^{\circ}\text{C}$ the ice crystals grow and easily turn to a star-shaped snow crystal. In lower temperatures they get a more round shape and in higher temperatures the classic form can change over to a three armed formation. Close to $0\text{ }^{\circ}\text{C}$ they tend to get a moistly layer which make them easily stick to each other and form bigger snowflakes.

Changes in climate also create condense and damp on the rolling stock which e.g. can have an impact on electric traction equipment. Long tunnels can for instance hold temperatures up to $+10\text{ }^{\circ}\text{C}$ while the temperature outside goes down to $-20\text{ }^{\circ}\text{C}$. A specific case for the Nordic countries regarding humidity is even specified in the high-speed rolling stock Technical Specification for Interoperability (TSI). The TSI states that the sudden changes of the air temperature local to the train shall be considered for a maximum variation of $60\text{ }^{\circ}\text{C}$.³

There are of course other weather situations that in some specific cases can cause worse effects. Just coldness or strong wind alone is not a big problem but in combination with other winter climate conditions the case can get much worse. Very low temperatures however (below $-30\text{ }^{\circ}\text{C}$) nearly always have negative effects on materials, components or systems such as rubber, sealings, lubricants, current collection etc.

2.2 SNOW PACKING

Snow packing occurs mainly in the bogies and the underframe. It will affect both the bogie movements and the movements within the bogie as well as the components placed underneath the floor of the carbody. A snow filled bogie is shown in Figure 3.

The problems in conjunction with packed snow and ice are related to blocked movements, squeezed and damaged components and reduced accessibility for maintenance. Also the running dynamics of the vehicle will be affected. This is due both to the increased weight and the blocked movements in springs, dampers, tilting mechanisms and other bogie movements.

² Photo from DB in report 'High-Speed Train Operation in Winter Climate' (2006)

³ Lerouge, B & Alibert, B (2005). *Draft Revised HS RST TSI (main text)*. Brussels: AEIF 22.12.2005.



Figure 3. Snow packing in a German bogie VT 605.⁴

Through site investigations in Japan it has been shown that snow and ice build up very fast under the vehicle floor when the daily average temperature drops below -4°C and the daily snowfall exceeds 3 cm. This is described in Figure 4 below where the amount of accreted snow and ice masses have been set into four levels: $A < B < C < D$.

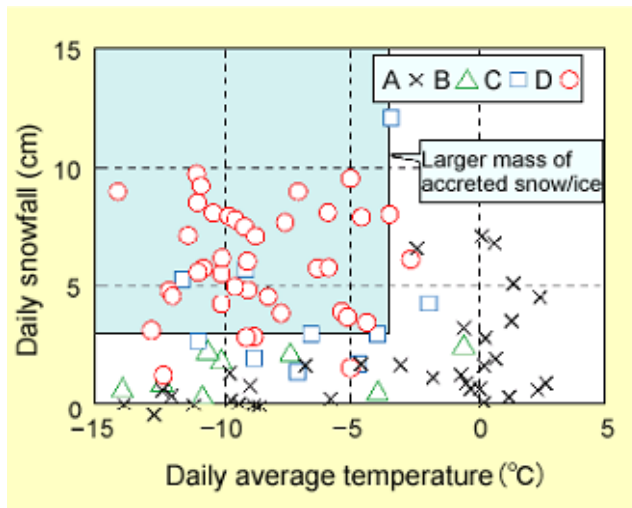


Figure 4. Relationship between amount of accreted snow and ice and daily average temperature⁵.

During these conditions the density of a mass of an accreted snow and ice came to stretch between $150 - 900 \text{ kg/m}^3$ with a maximum weight of approximately 15 kg. This relationship between weight and density is shown in the following Figure 5.

⁴ Photo from DB in report 'High-Speed Train Operation in Winter Climate' (2006)

⁵ Railway Technical Research Institute, Tokyo Japan (2004). *Clarification of Phenomenon of Ballast Thrown up by Snow/Ice Falling from the Train.*

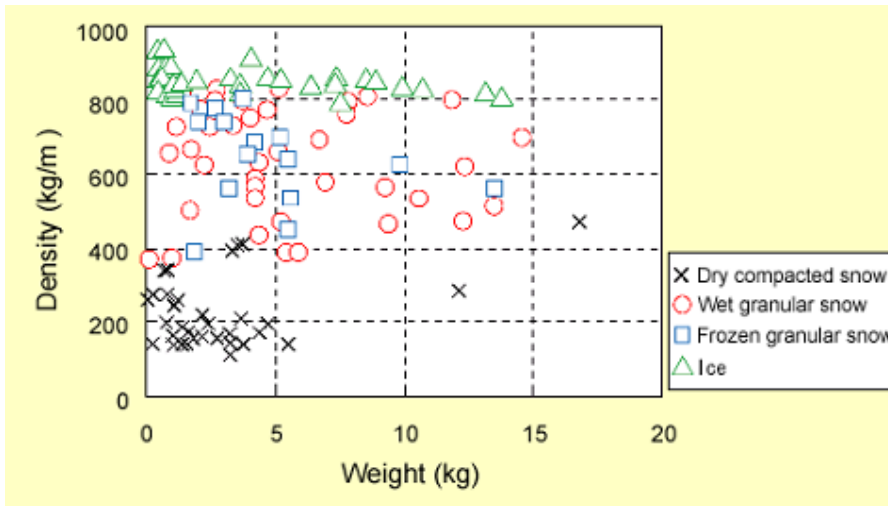


Figure 5. Relationship between weight and density of accreted snow and ice masses (by snow condition)⁶.

Snow and ice in bogies and underframes must be reduced as far as possible. Proposed solutions:

- Surfaces that need to be free of snow and ice due to movements can e.g. be covered with plexiglass on a thin foam rubber layer. Any ice formation on these flexible plastic covers will crack and fall off for an applied force on the ice, see Figure 6 below.



Figure 6. The thin plexiglass layer can be seen on the top of the bogie frame of a Swedish X2 trainset. The primary rubber suspension can be seen below to the right.

- In general, rounded surfaces as well as low friction surfaces are less subject to the build up of snow and ice and are therefore preferable.
- Deformable low friction covers, for example made by poly-carbonate mounted on an elastic layer, has shown very promising effects to reduce snow packing on Swedish Class 50 EMU:s.
- Avoid flat surfaces that move towards each other. A sharp edge is preferable when it comes to breaking the ice, see following Figure 7.

⁶ Ibid.

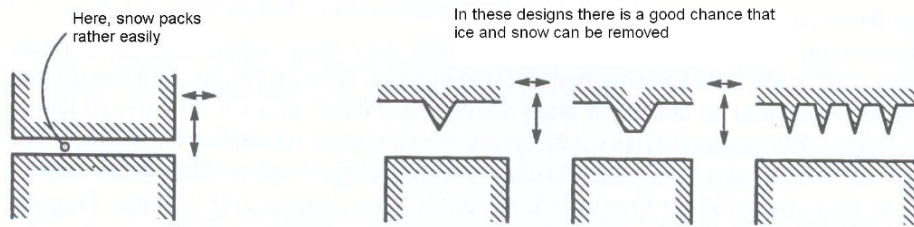


Figure 7. Examples of different surface designs⁷.

- Anti-icing methods have been tested to prevent the build up of snow and ice i.e. the surfaces have been covered with a layer of propylene glycol or silicone. The methods seem promising so far and are further described in Chapter 2.10.3 'De-icing'.
- A cellular rubber fill can be used in holes in the bogies and around components in order to prevent snow gathering.
- Tests have been made with bellows around the whole upper part of the bogie on the X2 trailing bogies with tilt equipment.

As long as the bellows are unbroken there is a positive effect but as soon as they break the whirling snow starts to pack inside even more than without the bellows. All the bellows are now dismantled.

- An open bogie design is favourable as it gathers less snow than a fairly closed design.
- Spoilers in different positions and of different design can be used to change the wind and snow flow around the bogie and carbody as well as around bogie and carbody components. This however must be tested and must function in both directions.
- Stagnation points concerning the relative wind speed in the bogies will adhere snow and shall therefore be avoided. This must be taken into consideration over the full operating speed range for the vehicle going in both directions.
- Tests have been performed with some type of "Japanese paint" which should reduce the amount of snow that clings to a surface. The result has not been promising so far.
- Tests have been made with electrical heating of areas where the build up is extra problematic, but the water from the melted snow can give problems somewhere else as it whirls away.

Some information indicates that heat is used on special locations on some Japanese trains with the purpose of preventing snow and ice from accumulating. An example of this is shown in the following Figure 8. This kind of procedure with heated surfaces has also been tried in Sweden. However, these tests have been interrupted due to the large energy consumption and the problem with uncontrollable melting water. The lesson from this was once again that ice build-ups on trains cannot always be prevented, but the effect of ice can be minimized.

⁷ Andersson, Evert & Berg, Mats (2003). *Järnvägssystem och spårfordon del 2: Spårfordon*. Stockholm: KTH

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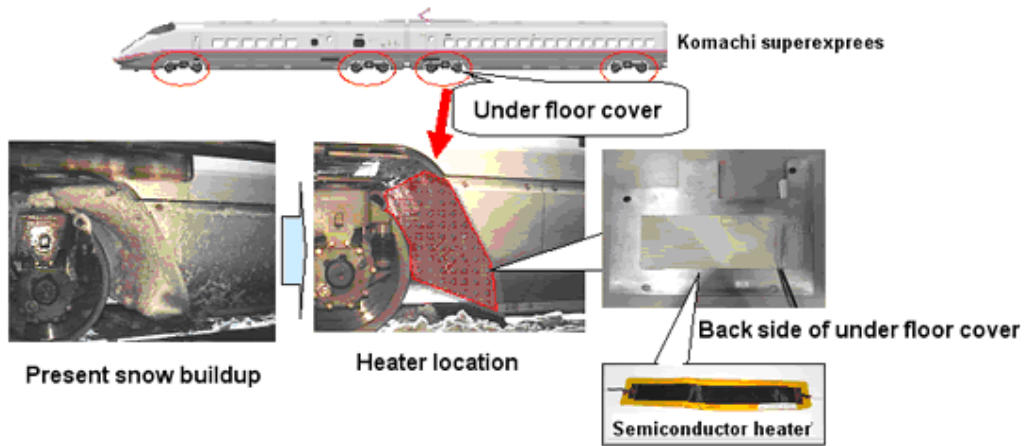


Figure 8. Japanese heating system to prevent snow build up under Shinkansen trains⁸.

2.3 BOGIES

The bogies are exposed to the outer climate, i.e. low temperatures, dry and wet snow, ice and strong winds. Bogies will also be hit by ballast stones and by obstacles on or very close to the track. The bogie designer must take all these aspects into consideration including the extra weight of some hundreds of kilos of ice and the possibly reduced ability for motion in the suspension. The ice that builds up in the bogie can in worst cases break or tear off cables and components as well as block necessary movements, see Figures 9 and 10.



Figure 9. A Swedish Class X2 bogie with snow and ice gatherings, in the beginning of the ice build-up.

⁸ East Japan Railway Company (2006). *Preventing snow buildup under Shinkansen trains*.



Figure 10. Snow and ice gatherings in a German VT 605-bogie after some time of operation.⁹

2.3.1 WHEELS, AXLES AND AXLE BOXES

Wheels, axles and axle boxes are all vital components for the safe running of a train.

WHEELS

Flats on the wheels are in the winter period usually caused by brake shoes or pads frozen to the wheels or discs after a train has been braked to stand-still. When the train is started again one or more axles might not rotate. Such a disturbance can be very difficult for the driver to identify. Also a not fully released brake (for instance due to ice blockings) will heat up the brake disc or the wheel rim, which in the end most likely results in damages.

Occasionally during winter, there can also be low adhesion causing wheels to slide on the rails.

Wheel flats in very cold climate can damage the rails and in worst cases break a rail every time the flat hits the rail head. This problem is to some extent reduced with modern and less brittle rails. On the other hand, smaller flats left unattended may also in the long run damage the axle bearings.

To avoid these problems it has been suggested to:

- Have a durable wheel slide protection system installed.
- Shorten the inspection intervals of wheels and brakes systems during the winter period to be able to act before small damages develop too big and costly breakages.
- Let trains that stand still on horizontal tracks have released brakes if possible.
- Use hot wheel and wheel flat detectors to reduce the risks for damages and derailments. Alternatively an onboard detection system for hot wheels and wheel flats is recommended.
- Heat the sand and the sand pipes used to increase adhesion to improve the function in winter climate. Mechanically protect sand pipes from ballast and ice projectiles.

AXLES

Initial cracks in axles can be caused by hits from the ballast. Alternatively ballast stones can get stuck for instance between an axle and a traction motor or a piece of frame work in the bogie. While the axle is rotating, the piece of macadam may cause a scratch around the axle. Cracks and scratches can lead to axle failure and severe derailments.

⁹ Photo from DB in report 'High-Speed Train Operation in Winter Climate' (2006)

Trains that operate on different rail gauges usually have wheels that can be displaced between two different axle positions. For the Talgo-trains in Spain and France this process (unlocking the wheel from the axle – sliding the wheel to the new position – locking the wheel to the axle in the new position) can be done automatically while the train moves slowly through a gauge changing station. The locking is a delicate operation and snow or ice blocking the movements cannot be accepted.



Figure 11. A Talgo running gear subject to snow and ice build up during a winter test.¹⁰

Figure 11 shows a Talgo wheel subject to snow during tests with different methods to de-ice before the gauge changing. The picture indicates that some measures have to be taken, either to hinder the build-up or to de-ice after a build-up, before the gauge changing can be done successfully.

Proposed measures to reduce axle damages in wintertime are as follows:

- Mounting of some type of rubber or plastic protection around the axle. However, such an arrangement makes a visual inspection of the outside of the axle impossible.
- Mounting of a protection above the axle, making it impossible for a piece of macadam to get stuck and destroy the axle surface, see Figure 12 showing an axle for a Norwegian class 71.
- Increasing the regular axle inspections during winter conditions.
- Taking measures to prevent the macadam to move, see Chapter 3.7 'Ballast pick-up'.
- For axles used on different track gauges, prevent the mechanisms from snow and ice as far as possible. Where this is not sufficient, electric heating is proposed to melt snow and ice in critical positions. The heating could be active just before and during the gauge changing process to avoid melting water to blow away and freeze somewhere else. Also too much heating normally has a negative effect on the grease. See also Chapter 2.10.3 'De-icing' for other de-icing methods.

¹⁰ Information from Talgo. *De-icing systems in gauge change wheelset*



Figure 12. Axle protection device.

AXLE BOXES

Axle boxes have to be sealed also when there are big temperature changes. Boxes and seals must be capable to withstand water and moisture both while running in high speed and while being de-iced in a workshop. If water is used for de-icing, poorly designed ventilation holes for bearing ventilation can be the reason for water ingress into the grease. Water in the grease damages the lubricant and thus the bearing in a much shorter time than originally expected. Therefore:

- The axle box design must be fit for purpose, i.e. if de-icing with cold or hot water is foreseen the axle boxes must tolerate that.
- The use of hot box detectors is of importance since damaged bearings can be identified in time.
- The use of an onboard detection system for hot axle boxes gives the driver the information directly and is independent of the distance between the detectors.

2.3.2 SUSPENSION SYSTEMS

The suspension system consists of a number of components out of which the primary and the secondary suspension, the dampers and the anti-roll bars will be discussed from a winter perspective below. Following Figure 13 gives an example of the tough conditions the suspension systems must withstand.



Figure 13. Bogie and carbody covered with ice.¹¹

PRIMARY AND SECONDARY SUSPENSION

The primary and secondary suspensions are needed to keep the track forces within the allowed limits and to get a comfortable ride. Snow and ice can partly or fully short circuit the suspension and give higher track forces and bad running comfort. Low temperatures at winter time can also affect the spring stiffness. To avoid such winter problems, the following measures have been recommended:

- Use a design that is collecting less snow and ice. This concerns bogie frames, rods, supports, connections etc.
- De-icing must be done at appropriate intervals.
- Prevent snow and ice to build up on surfaces moving towards each other, see Chapter 2.2 'Snow packing' as well as the Figures 7, 14 and 15.
- The use of covers around coil springs will prevent them from being packed with ice and snow giving reduced suspension (problem: a visual inspection will be more difficult); compare Figure 13 and 14.
- Where rubber springs are used, the stiffness coefficient must allow for low temperatures.
- Components for height level control in conjunction with air springs must be placed where ice and snow will not break them or block their movements.

¹¹ Photo from report 'High-Speed Train Operation in Winter Climate' (2006)



Figure 14. Snow covers both for the secondary coil springs and for closing the gap between the carbody and the bogie frame at the Finnish Sm3.



Figure 15. Snow covers/bellows around the primary suspension of the Norwegian BM71 seen from two perspectives.

DAMPERS

Many hydraulic dampers, especially the axle box dampers, are located in very exposed positions (see for example Figure 15 above) where they easily can get hit by ice and ballast. Proposed measures against these winter problems:

- Use mechanical protection around exposed dampers.
- Make sure that the damper oil and the sealing is suitable for low temperatures.

ANTI-ROLL BARS

Anti-roll bars are mainly used from a comfort point of view but also to prevent large lateral deflections of the pantographs. Nevertheless their rods and bearings need to be able to move and rotate and not be hindered by ice and snow. Proposals:

- Use bearings for the anti-roll bars fit for purpose. Their location sometimes makes them difficult to inspect when there is a lot of snow and ice.
- To reduce the risk of snow packing or freezing at anti-roll bars, sufficient distance must be kept between the arms and rods and the bogie frame and other components.

2.3.3 TILTING OF THE CARBODY

Tilting trains are used to increase speeds on lines with many curves. This section deals with the specific problems that concern the tilt mechanism and the measuring device for the tilt angle.

TILT MECHANISM

In Scandinavia most tilting trains have an active hydraulic tilt system. If snow and/or ice starts to build up, the tilt mechanism can be blocked and the full tilting angle cannot be achieved. This makes it necessary to reduce train speed or run with reduced passenger comfort.

The need for the anti-tilting of a pantograph is commented in Chapter 2.9 'Pantograph'.

Some tilting trains have less winter problems with the tilt systems than others. This may depend on the region where they are run, but it is most probably an effect of how well the tilt system can be protected from the build-up of snow and ice and how well the tilt control system works in winter climate.

Proposals for good winter reliability:

- The hydraulic systems must be designed to work in a wide temperature range.
- Prevent snow from disturbing the tilt mechanism.

This can be done either by having a very good sealed design around the tilt mechanism to prevent the snow from entering the area, or by making the area very open to make sure the whirling snow just blows away. In Figure 16 an example of a rubber protection is shown.
- Make sure that water squirting from for instance brake discs not hit joints etc. in the tilt mechanism and freeze to ice.

This can be prevented by putting splash covers on well tried-out locations. As it is difficult to foresee how water behaves at high speeds under the train, it is more or less necessary to make tests to find the best locations.
- Prevent snow and ice to build up on surfaces moving towards each other, see Chapter 2.2 'Snow packing'.



Figure 16. A rubber seal is mounted to prevent the snow to come further into the X2 tilt mechanism.

MEASURING DEVICES

To get the best riding comfort, the tilting shall be optimized as regards when and how fast it shall work. Measuring devices are used to give the right tilting angle and the correct timing. For good functioning it is important that:

- Devices for acceleration measurements and angular measurements are placed where ice formations will not crash or disturb them or their connectors.
- The cabling is well protected.
This means that there must be a protection from an electric and a magnetic point of view as well as from hits by ballast stones, ice blocks and other obstacles. Also the possibility of cables getting squeezed between moving parts such as rods for the tilting etc. covered with ice, must be taken into consideration.

2.3.4 RUNNING DYNAMICS

Snow gathering in the bogie will affect the running performance by reducing the spring movements, reducing the tilt angles on tilting trains and by the extra weight. The accumulated snow turns into ice due to the pressure from surfaces moving towards each other and/or from changes in the temperature. The blocked movements and the increased total weight will cause poorer running dynamics in the form of increased track forces, and reduced riding comfort as the speed is increased.

TRACK FORCES

Snow accumulation in the bogies and the underframe together with coldness may, apart from other aspects, have the following effects on the track forces:

- Reduced bogie movements due to snow and ice accumulation may increase the track forces and the forces between components on the vehicle to unacceptable levels.
- The increased stiffness in cold climate affects both the suspension system in the vehicle and the stiffness of the track, including the track bed. The higher stiffness increases the track forces. It may also affect the vibration frequencies of the wheel-rail system.
- The extra weight in bogies and carriages will increase the track forces.

Proposed solutions to these problems are to use:

- Preventive measures to reduce snow packing, see Chapter 2.2 'Snow packing'.

- Preventive de-icing. This has been tried to reduce the build up of snow and ice and is further described in Chapter 2.10.3 'De-icing'.
- During the bogie design phase, some extra weight representing snow and ice accumulations, ought to be included in different calculations.

RIDING COMFORT

It is necessary to allow for the movements between the bogie and the carbody to get a comfortable running. Figure 17 shows a bogie where the snow packing has started but probably not yet affected the riding comfort.



Figure 17. Snow packing in a Class X2 bogie.

To maintain a comfortable train ride the following has been pointed out as important:

- The build up of snow that later turns into ice must be prevented as far as possible to avoid a poor riding comfort.
- Shortcuts in the suspension system caused by snow and ice must be avoided or there will be increased noise level in the passenger compartments, see Chapter 2.3.2 'Suspension systems'.

2.4 BRAKE SYSTEMS

The brakes are part of the safety system whose function must be guaranteed regardless of climate. This is on the other hand not always the case in practise since there are influencing winter problems.

In this chapter some general important considerations concerning brake systems will first be pointed out, followed by the problems concerning disc and magnetic rail brakes.

The basic brake system is a pneumatic friction (adhesion) brake which involves winter problems such as freezing of air and moving parts and heat generation in the bogie/underframe.

If the compressed air system holds water it risks freezing or getting ice plugs in air tanks, drainage and gaskets. Other problems concern the use of inappropriate material or material combinations that shrinks and/or stiffens in cold. This can bring about un-tight air pipe couplings which make the reloading of air pressure take a long time and frequent recharging. In long trains this can cause difficulties to release the brakes. In the worst case the air cannot be reloaded at all, meaning that the train is not allowed to run. If the brake cylinders are not tight the braking effort can be reduced.

Unsuitable material can also result in a less efficient and slower brake movement that means less brake force. This could also be the result of a bad choice of lubrication. The restrained brake movements, concerning for example lever arms, can in addition be caused by snow and ice accumulations (for measures against snow and ice accumulation, see Chapter 2.2 'Snow packing').

The standard air coupling between vehicles is often achieved by the means of rubber hoses and a sealed air coupling. In many applications the hoses have to be bent to be able to couple or de-couple the compressed air. Therefore not only the functioning of the air coupling must be guaranteed in low temperatures, but also the hoses have to be bendable for all specified temperatures for the vehicle.

The reviewed more common or well known problems have been proposed to be avoided through the following measures:

- The compressor should be well covered and fitted with air dryers and filters. Since the compressor is a vital part of a train, redundancy is recommended as well.
- Rubber in hoses and seals must give air tight connections during all specified temperatures. Also the ability to bend the hoses must be taken into consideration.
- Some pneumatic components of the brake system may need to be placed in protected areas.

This is a design measure that protects from snow and ice build-up. For example the components can be mounted on panels inside boxes in the underframe.

2.4.1 DISC BRAKES

During wintertime the disc brake performance can be lower compared to other seasons. In Sweden this problem was raised in the middle of the 1980's, when coaches with disc brakes became more common, and it has since then been a delicate topic. The nature of the problem is very severe as it has happened in both Norway and Sweden that stop signals have been passed due to disc brakes with reduced braking effort. The problem is expected to get worse with higher speeds as the brake distances then increase further. Another issue is that, if the problem with disc brakes in winter climate is not managed, it might be possible that operators are forced to have separate winter and summer time schedules with lower speeds in the wintertime if the train speeds increase further.

Significant for the problem is the occurrence of snow smoke. In such a case it is common that water, snow and/or ice build up on the brake discs. Eventually a film of water – more water than can be managed – forms on the disc surface causing the brake pads to aquaplane. This reduces the braking performance and can make the train stop beyond the intended point. Tests performed in Sweden¹² have shown that a very slow build up of the brake force may occur, which can be seen in Figure 19 below.

The Swedish State Railways has made several winter tests in order to solve the problem with disc brakes in snow smoke. The testing activities were quite extensive and included a number of design measures that were investigated. Among these were for example disc covers, disc rings, various skirts and a polishing brake. Out of these, the disc covers appeared to be the best solution.

In Sweden each new train composition that is taken into service must undergo a deceleration test. The service-brake is tested as soon as the trainset reaches normal operating speed. The outcome of the test may require adjustments of ATC (Automatic Train Control) settings and can result in a speed restriction. If the driver at any time suspects a reduced braking performance, he is instructed to do another deceleration test.

During operation it is in some cases hard to say whether the reduced brake performance is entirely due to the disc brakes. The adhesion may also be influenced as snow smoke may decrease the friction between wheel and rail. Test results have been conflicting on this specific matter. Some tests imply that snow smoke decreases the adhesion while other tests have not given results supporting this¹³.

The new disc-braked DMU:s on the Västerdalsbanan in middle Sweden had to be taken out of service due to brake force fall-outs during their first winter of operation 2006. The investigation showed that during certain weather conditions with snow and snow smoke the brake force was reduced. The trainsets are now back in service and a snow brake has been added, see below.

It is today suggested that the disc brake problem can be dealt with through the following measures:

¹² Gustavsson, Sven-Erik (1997). *Skydd för skivbromsar som utsätts för snörök*. SJ Laboratorierapport 9705-39p.

¹³ Pettersson, Kalle & Wännman, Jan (2000). *Vinterprovtaget 1999/2000*. SJ Rapport R00-11.

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- Instruct drivers on how to brake at the occurrence of snow smoke.

In order to remove the ice and water film between the brake pad and disc the driver should exercise the brakes slightly. The pressure and heat generated by this procedure eventually gets rid of the ice and water. Drivers can also be instructed to perform more deceleration tests in order to ensure proper brake performance. Another method is to initiate the braking procedure in advance that is to say to apply the brakes earlier than normally before a planned stop.

- Install snow brakes.

Instead of informing the drivers how to break with the aim of removing the water and ice film an automatic function could perform the task. The function – called snow brake – automatically applies brake in intervals in order to maintain a better contact between disc and brake pad. The snow brake can for instance be set to be activated at special conditions such as when the temperature turns below zero degrees and the speed exceeds a certain level. This application has a great value in replacing the corresponding manual operation, but it means extra wear, extra energy consumption and the traction performance can be reduced in some special situations.

This design could be compared to the polishing brake that also has been tested in Sweden. In these tests the solution was criticized as it generated further melting water that froze especially at the braking mechanism.

- Provide trains with better brake pads.

A better contact between brake disc and brake pad can to some extent be accomplished through the use of brake pads that more effectively lead away water. Some trains are equipped with both better brake pads on the motor axles and snow brakes on the trailer axles.

- Install disc covers.

The brake discs can be fitted with covers as seen in the following Figure 18. In the late 1990's disc covers were tested in Sweden and the measure proved to be quite successful. The appraisal was done that disc covers have a positive effect as regards reducing the risk for reduced brake effort during winter weather, however they do not solve the problem entirely. There were also some discovered problems; they complicate inspections, tend to gather ice and can inhibit the braking performance in severe coldness during long runs.

A result from one of the tests with disc covers can be seen in Figure 19, showing that still after 60 seconds only around 30 % of the brake force has been achieved on the unprotected disc compared to the one carrying disc covers.

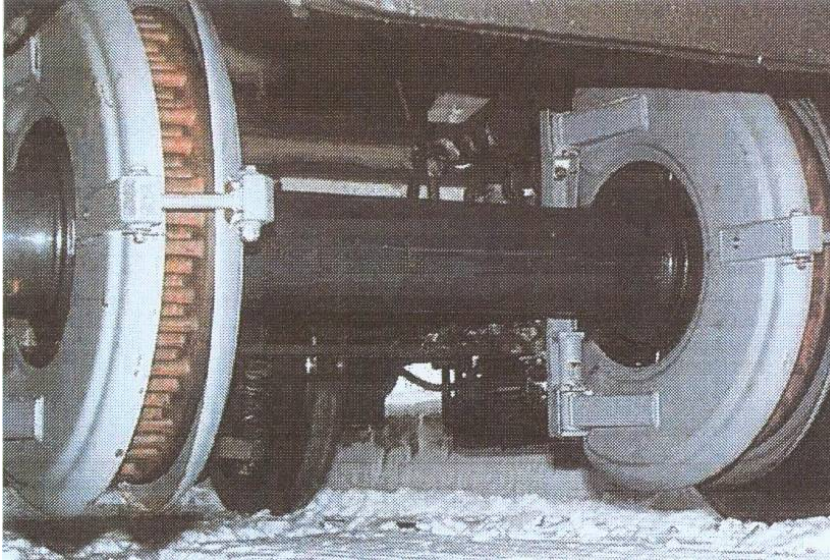


Figure 18. Disc covers for disc brakes¹⁴.

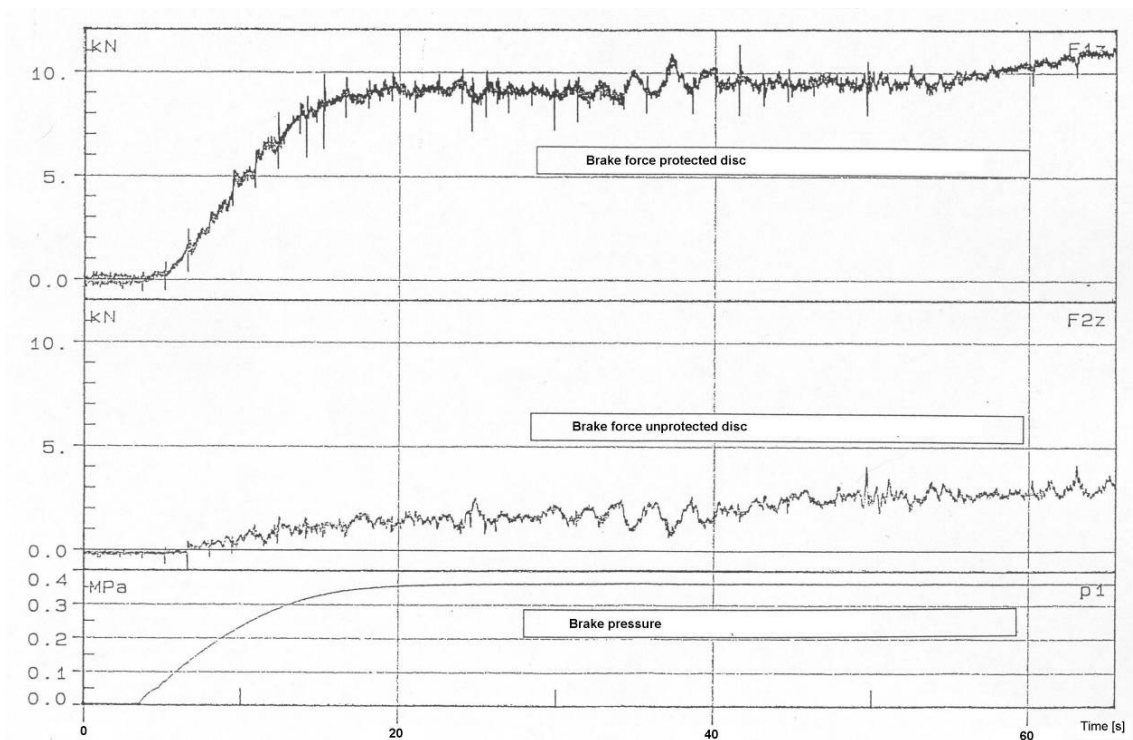


Figure 19. Full brake in 100 km/h with brake forces for disc brakes exposed to snow smoke.¹⁵ The disc protected by disc covers achieves full brake force, between 9 to 10 kN, during the whole brake procedure. The unprotected disc on the same axle has a very slow build up of the brake force. Still after 60 s it is only approximately 30% of the demanded force.

¹⁴ Ibid.

¹⁵ Gustavsson, Sven-Erik (1997). *Skydd för skivbromsar som utsätts för snörök*. SJ Laboratorierapport 9705-39p. The graph has been translated into English and is therefore slightly modified.

Another winter problem with disc brakes appears as water is being thrown from the discs and freezes in the brake mechanism. The accumulated ice and snow then can cause lower brake forces and damage brake cylinder bellows and seals. It is therefore of importance to:

- Equip disc brakes with splash covers.

2.4.2 MAGNETIC RAIL BRAKES

Snow smoke is also a hassle for the magnetic rail brake. The whirling snow clings to the bogie area where it freezes and subsequently gathers more snow and ice. The brake problem occurs when the snow and ice accumulations keep the magnetic brake in place preventing it from falling down towards the rail. This problem with ice in the bogie, that influences the magnetic rail brake, has also been identified e.g. in Germany.

Magnetic rail brakes can also become unusable when ice and snow accumulate at the underside of the brake. The brake slide on the rail and cannot generate the intended brake force.

Normally, a non working magnetic rail brake results in speed restrictions, for example from 200 to 160 km/h. However, during operation it is hard to decide if a magnetic rail brake is not working properly since it is not used as often as the disc brakes.

The following measures have been put forward to facilitate the problems:

- Apply heat to the magnetic rail brake.
Several magnetic rail brake designs contain heat that is applied in intervals. This seems to work in some situations. Nonetheless heating is expensive and can mean trouble with melting water. There are also examples where the heating has been insufficient and the brake has been blocked by ice and snow from reaching the rail. It is therefore of importance to make sure that the heating and power intervals are set correctly.
- Protect magnetic rail brakes from water.
The magnetic brake must be protected from water that comes from both the brake discs and the wheels. This can e.g. be accomplished through the use of splash covers.
- Inspect, exercise and if necessary de-ice the brake at end stations.
The ice attached to the underside of the magnetic brake can be removed as the brake is exercised. It is therefore recommended to put the brake into effect and examine it at for example end stations.

The winter problems with both the disc and magnetic rail brakes unfortunately lead to uncertainty concerning how the emergency brake should be handled and for that reason it might be necessary to:

- Investigate how the emergency brake should be managed.
During some winter conditions, the function of all types of brakes cannot be guaranteed. Winter can completely or partially put both disc brakes and magnetic rail brakes out of function. This may cause severe consequences that increase with the speed. It also leads to uncertainties concerning how the emergency brake should be handled.

2.5 CARBODY

To get a good indoor climate comfort for the passengers the insulation of the carbody must be sufficient in the lowest specified temperature for the vehicle. The new German built high speed trains for Russia are foreseen to run in temperatures down to -50 °C and the thickness of the carbody insulation is doubled. With these temperatures it is necessary also to consider glass and door insulation as well as the heat radiation through the windows. Also notice that some materials have different characteristics in such low temperatures compared with -10 to -20 °C.

2.5.1 PASSENGER COMFORT

Passenger comfort includes many aspects as riding comfort, temperature, spacing, noise etc. From a high-speed winter perspective most of these factors are beyond the scope for this study. Here only aspects on cold climate are mentioned:

- The ventilation has to be designed to keep a normal air humidity also when lots of snow is drawn into the compartments.
- Passenger and driver cab ventilation intakes must be designed so that they do not get filled with snow and that the snow does not get inside, melts and causes problems. The intakes must be designed to function in both directions.
- The heating and insulation shall be designed for maximum speed in both directions in cold windy climate both for the passengers and the driver. The heating must also be sufficient when the train stands at a platform with open doors. Alternatively measures, see further down.
- Although the need for heat is big at low outdoor temperatures, it is important that the components that can be in contact with passengers, luggage etc. not get too warm to avoid injuries, damages and risk of fire.

2.5.2 DOORS AND STEPS

When platforms are not cleared in a proper way snow gets on the steps and into the trains together with the passengers. Both the snow and the water from the melted snow cause a lot of problems in door entrances. Also sand etc., which has been put on icy platforms cause problems when it gets into the vehicles.

DOORS AND DOORWAYS

From a winter perspective the following shall be considered:

- Doors must be tight to prevent snow drift inside.
This also means that both door and door sealing must be able to work as intended in severe winter conditions. Materials such as rubber are affected by the coldness and can obstruct door movements.
- Sand as well as ice and snow must be prevented from blocking door movements.
- Although the door blades shall be light, the insulation must be good as the temperature difference between inside and outside easily reaches 50 degrees Celsius with a high cooling effect on the outside.
- A passage lock, with for instance hot air at the entrances or an extra door to the passenger compartment, is suitable for especially trains with frequent stops with door opening and/or big entrance doors.
- To keep a pleasant indoor climate at low outdoors temperatures it is necessary to reduce the time at platforms with open doors when nobody is entering or leaving the train.

STEPS

There are two types of steps, fixed or movable. Independent of which solution is chosen, the steps must be safe to step on even if a lot of snow is dragged into the door entrances where it starts melting and gets slippery. Movable steps must function whether it is summer or winter. Therefore:

- The amount of snow, ice, sand etc. getting into the vehicle through door entrances must be reduced as far as possible.

Snow and ice turns into water which needs to be taken care of. Normally the humidity is ventilated away by a sufficient ventilation. Sand hinders the functioning of doors and movable footsteps and can destroy the mechanisms. The risk can be reduced by different types of seals.

- Make sure steps are not slippery.

To avoid passenger accidents steps must not be slippery due to snow and ice when people are passing through the doorways. Slippery steps will make the stopping times longer as the passengers have to be more careful when they enter or leave the train.

A possible solution, where applicable, would be to use perforated steps or surfaces in order to reduce the risk for snow and ice accretions.

- Steps folded or drawn into the carbody need to be heated to clear them from snow and ice till the next station. All equipment in this area must stand the fairly high temperatures that might arise.

2.5.3 COUPLERS AND GANGWAYS

The couplings and gangways between two vehicles can be of many different kinds. Regarding the couplers, only couplers that are used for coupling and de-coupling in normal operation are discussed below and permanent couplers are excluded.

COUPLERS

Automatic couplers of different kinds are usually used between vehicles or sets of vehicles in all high-speed operations. First of all they take the longitudinal forces (traction and braking). Secondly there often is an electric low voltage coupling and an air coupling integrated in the automatic coupler. To secure the functioning in winter conditions:

- The mechanical parts need to be lubricated especially for winter conditions.
- The electrical part of the coupler head needs to be heated to prevent snow and ice to interrupt the electrical signals.
- The air connection shall be protected with a tight cover when not coupled.
- When not in use the coupler shall be protected from snow and ice.
- There can be a conflict between heating the coupler parts and lubrication of the same parts which has to be solved.
- The coupler pocket must be free from snow to let the coupler arm move up and down and sideways; compare with following Figure 20. This could be achieved with a rubber membrane covering the coupler pocket.
- Rescue couplers are often kept in underframe boxes when not being used. Make sure that a rescue coupler always can be brought out even if a platform or a lot of snow and ice partly block the opening.



Figure 20. A German class VT 605 with snow packed in the coupler pocket. ¹⁶

GANGWAYS

Coldness puts extra demands on the gangway why the following issues should be regarded:

- From a passenger point of view the gangways need to be heated, lighted and isolated.
- The gangway material must allow for low temperatures without getting stiff as the vehicle must be able to negotiate all specified horizontal and/or vertical curves.
- The gangway material shall not wear abnormally when subjected to motions at low external temperatures.

2.5.4 TANKS, HOSES AND PIPES

Trains can always be subject to temperatures well below freezing, meaning that the on-board water systems must be able to handle that.

TANKS

Winter perspectives on tanks mainly include unprotected tanks hanging underneath carbodies. It has been recommended that the following shall be taken into consideration:

- Unprotected tanks underneath must be able to withstand hits from ice, ballast and other different obstacles without breaking.
- Heating and insulation is needed to prevent water tanks and WC-tanks from freezing while operating in cold climate.
- An automatic water tank emptying system shall be used in case the water temperature tends to drop below +4 °C for instance while being parked over night in cold climate. This goes for all fresh and waste water tanks.
- Toilet tanks must be designed to tolerate the maximum content which is fully frozen.

¹⁶ Photo from DB in report 'High-Speed Train Operation in Winter Climate' (2006)

- Make sure that there are no low points or valves that are not fully open where water can be captured when the automatic emptying system is activated. All tanks and valves must be emptied completely.

In many cars there might be onboard tanks as well, for instance under the roof. For such tanks it is thereto necessary to:

- Have the tanks insulated and heated if they are not placed where it is indoor climate.

HOSES AND PIPES

To avoid water leakage problems from broken hoses and pipes, the following should be considered:

- Hoses and pipes shall have enough insulation to the outside to ensure that they do not freeze when the vehicle is running at full speed in cold climate. Alternatively they must be heated.
- Unprotected hoses and pipes underneath must be able to withstand hits from ice, ballast and other different obstacles without breaking or have a sufficient protection.
- Pipes for filling, overflow or for emptying tanks must be prevented from ice build-up and freezing by covers and/or heating.
- Too small diameters should be avoided, since water in hoses and pipes with small inner diameter freeze easier than in bigger ones.
- Make sure that there are no low points or valves that are not fully open where water can be captured when the automatic emptying system is activated. Hoses and pipes must be emptied completely by the automatic emptying system.

2.5.5 UNDERFRAME

Passenger cars and multiple units have as much equipment as possible installed in the underframe or on the roof. Modern passenger car concepts – except low-floor vehicles – normally use underframes covered with skirts although the environment under the carbody is not always ideal. Notice that it is essential for the reliability in winter climate that the underframe is completely covered to protect the installed equipment from snow, ice and ballast pick-up.

The following steps have been proposed to reduce the risk for problems during winter conditions:

- The use of a large box, covering the entire underframe, can be a better solution compared to several smaller boxes. This is as it minimises the number of surfaces where snow can gather. A covered smooth underframe also reduces the risk for stagnation points, where snow will stick.
- Prevent snow from coming into the cabinets and boxes by having an overpressure in them.
Although all doors and hatches must be tight, they must be easy to open and close for the maintenance people. Make sure that they can be opened not only in a workshop, but also in the field and close to a platform where it might be very tight, especially with a lot of snow and ice.
- Make sure that all equipment placed in the underframe is designed to withstand problems related to coldness, if this is not a heated area.
- Skirts, boxes and other outer surfaces must be protected and be able to withstand ballast pick-up and collisions with ice, big animals and other obstacles in the track.
- The equipment in the underframe must tolerate de-icing, compare Chapter 2.10.3 'De-icing'.

2.5.6 SNOW PLOUGH

There are at least two purposes with a snow plough:

- To remove snow and ice from the track when necessary.
- To throw bigger obstacles and animals to the side. This will prevent them from coming under the vehicle thus reducing the risk for a derailment. It will also prevent them from being thrown

up the front and onto the roof and thereby reducing the risk for destroyed pantographs, overhead wires and electrical failures.

Collisions with big animals are much more frequent during a winter period with a lot of snow. The main reason for this is that it is more convenient for the elks and reindeers to move along the ploughed tracks than in the deep snow beside the tracks.

The design demands on the plough have to be specified for different types of operation. Both in Norway and Sweden a fairly big plough has been developed for locomotives fulfilling these demands. For different types of EMU:s and DMU:s the plough often is integrated in the design and is more an obstacle deflector than a snow remover, see Figure 21.



Figure 21. An Öresund train EMU Class X31 for the operation in southern Sweden and in eastern Denmark. The plough may function as an obstacle deflector but as a snow plough it looks like a poor design that does not manage to throw the snow to the side. The equipment behind it, such as the primary dampers seen to the left, is not protected.¹⁷

The following have been mentioned as important:

- The plough shall be designed to throw snow, ice and other obstacles to the side to avoid them from hitting equipment in the bogies or underframe or even to cause a derailment.

On the other hand the ordinary trains shall not be used as regular snow ploughing vehicles. That just results in the trainsets getting stuck in the snow. Figure 22 below shows a three-car DMU Class Y2 with a similar front as the Class X31 in Figure 21. The Y2-train got stuck on Christmas Eve 2010 due to too much snow on the line Linköping – Kalmar in the south-east of Sweden. The army had to rescue the passengers and the line was closed five days due to the blocking train.

¹⁷Photo from Kvällsposten 29 November 2010. *Vinter och tunnel satte stopp för tågen*



Figure 22. A Swedish DMU Class Y2 stuck in the snow on the Linköping – Kalmar line although the train has got four diesel engines of totally 1240 kW.¹⁸

- In order to prevent derailment the wheel load on the first axle must not be reduced when the plough is in action. The plough must be designed to minimize the risk of lifting forces due to snow packing in front of the plough. A sharp-pointed plough is good to push snow to the side, Figure 23, but may on the other hand cause big lateral forces when running through asymmetrical snow heaps.



Figure 23. A Norwegian E18 with a passenger train on a not cleared line section. The effect of the angled front plough can be seen as snow smoke thrown to both sides of the locomotive.¹⁹

- For best functioning the plough shall of course be mounted as close to the rail as allowed with respect to the gauge.
From this point of view a plough mounted in the bogie will be the best, especially for tilting trains. On the other hand, the forces on the bogie may become too high and snow might be pushed up onto the bogie frame. A combination of a both a carbody mounted and bogie mounted plough could be an optimum.
- Special care must be given to the design of both the front and rear plough concerning the air pressure between the ploughs and the ballast, see Chapter 3.7 'Ballast pick-up'. An opening in the middle can reduce the amount of snow that gathers on the rear plough's back side, see Figures 24 and 25.

¹⁸ Smålandsnytt SVT Kalmar 2010-12-28. *Kustpilen fast i tre dygn.*

¹⁹ Lokomotivmans Tidende nr 11/12-2008. *Avsporingen i Storekleven: Havarikommisjonens rapport*



Figure 24. A Swedish Rc locomotive with a standard snow plough heading a Stockholm-Oslo train. The tip is cut off. This is to give a free area for the person doing the coupling and decoupling. It has also the effect that the rear plough does not collect so much snow on the back side as there is a wind stream backwards through the opening.



Figure 25. A Swedish Class X40, where the area between the rear bogie and the plough is filled with snow. It can also be seen that a plough mounted so far in under the carbody is more an obstacle deflector than a snow plough.

2.5.7 TYPHOONS

Snow and water can create ice inside typhoons causing them to malfunction. Typhoons out of order in Sweden result in a speed restriction to maximum 40 km/h. In most cases typhoons are hard to reach when they are located on top of the roof close to the catenary. Therefore there is a problem to attend a malfunctioning typhoon during operation. That is why:

- Typhoons need to be either heated or encapsulated.
- The position shall be optimised due to wind streams in both directions.

- For locomotives the rear typhoon might be used if the front typhoon temporarily is out of order. There must in that case be a possibility for the driver to switch over to the rear typhoon and manoeuvre it from the driver's cab. This solution can not be used in multiple units.

2.5.8 REAR MIRRORS

Rear mirrors are used by the driver to see signals given by the train staff or staff at the station at the rear of the train. They can be replaced by video cameras giving the same function. In order to ensure a good view:

- Mirrors and/or video camera lenses/protections must be heated to avoid condense.

2.5.9 LIGHTS

Front and rear lights must always be visible. If the lights are out of order or cannot be seen due to snow or ice gatherings the consequence is a driving ban. Some light designs can get covered more easily than others, for instance xenon and diode lights that do not emit as much heat as regular light bulbs do. It has been proposed that:

- Lights should be heated or consist of regular light bulbs.

2.5.10 FRONT WINDOWS

The front windows need to be heated for the driver's sight in the winter time. On a fast train the air cooling effect is very high. The heating power must compensate for the cooling but also take the glass length expansion coefficient into consideration. The front windows must also stand the full heating at stand still, if not the temperature is adjustable. Eventual problems with a rear fully heated windscreen must be considered.

The windscreen wipers must be driven in such a way that the wiper motor is not destroyed if the wipers are frozen to the window.

2.6 COLLISIONS WITH ANIMALS

From a high-speed winter perspective only collisions with bigger animals are regarded as a specific winter problem. In the winter with lots of snow, elks and reindeers prefer the cleared tracks compared to the deep snow beside the lines. Therefore in the Nordic countries collisions are fairly common in the winter time. It has been said that some 80% of all collisions with big animals occur during the winter time.

A reduction of the risks is proposed by:

- Keeping fences along high-speed lines to keep the bigger animals out.
- Using "anti-elk-smells" along the line.

During the Winter Olympics in Lillehammer elks were kept away from the track with the use of wolf urine on sticks along the line.

However all collisions cannot be avoided. Whatever is run into, it must be hindered to come under the train to minimize the risk for derailment, see Chapter 2.5.6 'Snow plough'. When the worst comes to the worst, the train fronts must be designed to minimize the damage from a collision. Apart from the front itself, this includes the coupler and the eventual coupler protection, the plough and the front windows. The following also need to be considered:

- Eventual electric and air connections in the front or on the automatic coupler need to be protected.
- Steps to reduce carbody damages and make cleaning easy after a collision with animals shall be taken. It is recommended to have those parts in the front that often will get damaged, easily changeable to a relatively low cost.

2.7 CABLES

The majority of the cables exposed to the outside climate and environment are located between cars and around the bogies where a lot of snow gathers. Cables must therefore be able to cope with the tough conditions that these locations represent. This means first and foremost ice, snow and macadam stones that in one way or another hit the cables (for further information regarding striking stones see Chapter 3.7 'Ballast pick-up').

Eventually snow that sticks to the underframe and the cables turn into ice. Next the ice builds up even more snow and ice. In due course a cable can carry a large extra weight and risk breaking.

For tilting trains some cables might get extra long for example cables to angle measuring devices and can gather more snow and ice. Also ATC cables have proven to give problems as they, due to their location, are subjected to e.g. ballast pick-up.

Besides the extra weight, cables can get damaged or squeezed by accumulated snow and ice in the bogie areas as the bogies move. An example of this is illustrated in following Figure 26.

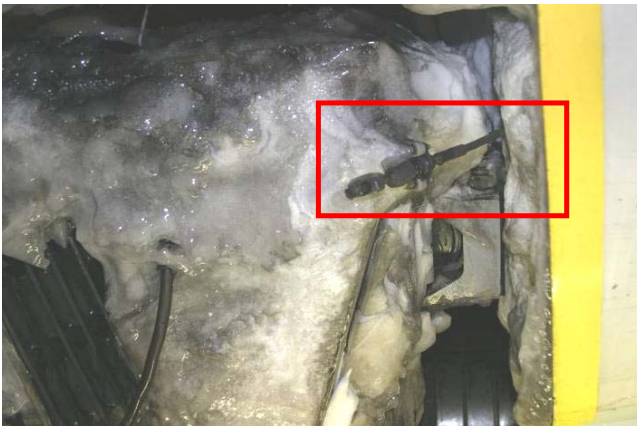


Figure 26. Example of a cable that risk getting squeezed between bogie and carbody on a Swedish tilting train.

To avoid cable problems the interviews performed suggest that following solutions should be taken into account:

- Eliminate as many free hanging cables as possible.
The problem could partly be solved if the amount of these cables were decreased. This could for example be accomplished by centralizing cables and by attaching them to the bogie centre through a bellows of some kind. This design would keep cables out of reach for snow and ice, but the design measure may possibly make maintenance more difficult.
- One option may be to place the traction motors in the carbody instead of in the bogie. Such a design eliminates some of the free hanging cables.
- Cables must be designed for the extra weight that ice and snow bring.
Nonetheless it is an experience of today that already strengthened cables or their connections can break from the extra load of snow and ice.
- Fit cables with protection
The spiral covers that cables in Figure 27 are fitted with protect against hits from ice and macadam stones. The protections are made by plastic or stainless steel.

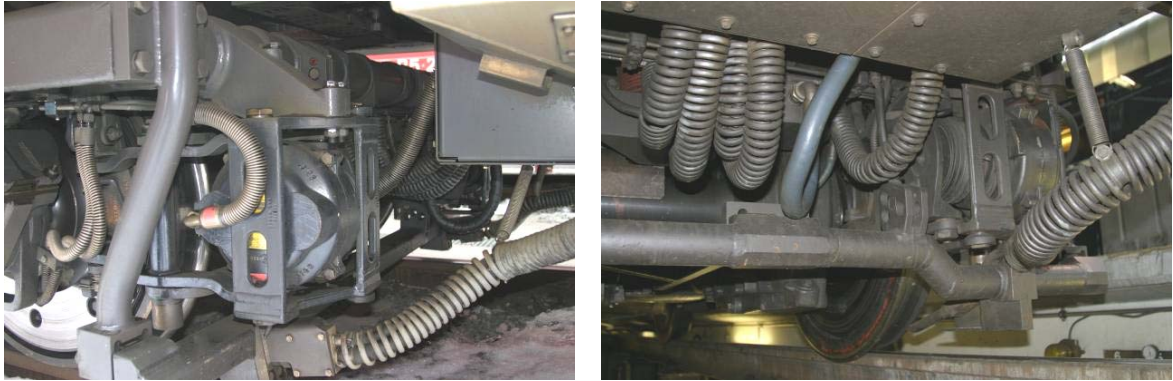


Figure 27. Cable protection devices on the Norwegian BM 71.

2.8 ELECTRIC TRACTION SYSTEMS

When it comes to the traction systems most interviews have made it clear that proper ventilation of motors and other equipment is of great importance. Moisture is very hard, if not to say near impossible, to keep out and for that reason it must be ventilated away.

2.8.1 MOTORS AND COOLING SYSTEMS

Most electric motor-related winter problems concern moisture. For example the forming of moisture at electrical components may cause poor isolation and short circuits. Water reaches the traction motors primarily through condense, cooling systems and occasionally as trains are de-iced with water. When water gets into a motor it can result in electric failures such as flashovers that can cause harm to the motor. This was very much the case of commutator motors, but will partly still hold for asynchronous motors with fully isolated windings. The isolation may be damaged by the voltage stresses in combination with moisture, dirt and ice.

Condense is primarily caused by temperature differences. A train that is taken either in or out of a workshop is often subject to condense. Temperature differences of 60°C are not unusual in these cases. There can be water drops that condensate over the whole train and sometimes even condensation inside the motors and on other electric or electronic equipment. The humidity inside a workshop can be very high when ingoing trains bring a lot of snow and ice into the building

The cooling system is an entrance for snow and consequently water. Snow can push inside to motors and blowers via cooling air intakes. The snow can then either turn into water or freeze to ice and may block the cooling system. The ice created can later on become a problem if it turns into damp air. It may also harm moving parts.

The Eurostar high speed trains (see Figure 28) running through the Eurotunnel faced chaotic problems the week before Christmas 2010. The trains have been running for 15 years but never had such problems as the night 18/19 of December 2010.

Five trains running from France to England broke down and got stuck in the tunnel and two had to be evacuated in the tunnel. There was intense snowfall in England and even heavier snowfall in Belgium and eastern France with temperatures below 0°C. The air intakes did not work properly and together with the air also snow and moisture was sucked into the cooling system which resulted in condensation inside the power cars when they came into the warmer tunnel section.

From the independent report afterwards the following is stated among others:

"In reviewing the causes of the breakdown of the trains, it has become apparent that the standard winter-weather procedures followed by Eurostar were not suited to the actual weather conditions experienced. The running maintenance procedures did not prove sufficient for the extreme winter weather conditions and not enough consideration was given to the fact that certain parts of these trains have suffered over the years. It is also clear that the design of the power cars does require high

*levels of ventilation whilst at the same time providing adequate protection for sensitive components, especially the electronic circuits. This has been proven to be inadequate.*²⁰



Figure 28. On an average day some 30 000 passengers use the Eurostar trains. Compare the snow smoke in Figure 1.²¹

The service of the Eurostar trains was suspended for three days with a first limited operation on the 22nd of December 2010. The independent report focus on three areas for improvements:

- Train reliability
- Evacuation and rescue procedures
- Managing disruption and improving communication.

In order to avoid electric problems in winter climate the following design principles have been recommended:

- Place air intakes high.

The snow smoke that surrounds a running train is most severe at the vehicle's lower parts. Thus, cooling air intakes should be placed high up at the roof. Alternatively they can be placed high up between the cars, especially in EMU:s.

Air intakes shall be fitted with filters.

In Figures 29 and 30 there are examples of rolling stock with air intakes placed high at the roofs.

- Make sure that air intake designs are appropriate for harsh winter climate.

Air intakes located for example in the bogie for non-forced cooling need filters that meet winter requirements. These filters must make sure that only air passes and not any snow. It has been experienced that some air intake designs adopted in other countries do not work in Scandinavian winter conditions.

²⁰ (2010) Eurostar independent review.

²¹ Ibid

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- Focus on ventilation instead of sealed designs. It is very difficult to make designs absolutely sealed as humid air is almost impossible to keep out. Electronic equipment should be installed in separate and well ventilated cabinets inside the vehicle as far as possible.
- The cooling effect from the cooling air can be too strong in very cold climate. The result can be that a traction motor not reaches the right working temperature. Optimise the ventilation in such cases by regulating the amount of cooling air or by other means.
- With the help of modern traction motor design (such as a permanent magnet motor) the ventilation of the motor can be simplified and less vulnerable to water and humidity. In the project “Gröna Tåget” this has been successfully demonstrated.



Figure 29. Above: High positioned air intakes on the Finnish Sm3.

Figure 30. Left: High positioned air intakes on the Norwegian BM71.

2.8.2 MOTOR CONTROL SYSTEMS

There have been problems were electronic equipment such as current converters, which have been exposed to snow. Normally being enclosed in the underframe, this equipment is rather well protected. Nevertheless if there is a built-in underpressure in this area snow will be dragged in and water can damage the electronics. To see to this problem:

- Motor control systems should be placed in protected areas such as cabinets with overpressure.
- It is important to keep the electronic equipment clean and dry especially in the winter time when condensation together with dust and dirt easily give short circuits. Compare the description about the Eurostar problems in Chapter 2.8.1 ‘Motors and cooling systems’.

2.9 PANTOGRAPH

The higher the speed is, the more delicate the current collection will be. If winter conditions are added to the current collection an even higher number of problems will arise.

It is recommended to have a redundant system, i.e. two separate pantographs for an electric train. If one gets damaged the other one can be raised and used instead. The need for this is normally higher in winter conditions. Compare also Chapter 3.6 ‘Over head wire’.

The pantograph consists of four sensitive parts:

- The carbon strip, giving the current transmission from the contact wire to the pantograph.

- The pantograph head with its suspension for a continuous current collection.
- The normally air operated pantograph's lower and upper arms and their linkage including the emergency drop, which automatically lowers the pantograph in case of a damaged carbon strip.
- For tilting vehicles – the anti-tilt mechanism.

2.9.1 CARBON STRIP

The wear of the carbon increases dramatically when there is rime on the overhead wire. Due to the arcing, this results in either the wear getting so big that the carbon breaks or the heat destroys the fastening of the carbon to the carrier. Hits from foreign obstacles can also destroy the carbon and the risk for tearing down the catenary with a damaged carbon strip is very big. Proposals to reduce the problems:

- Shorten the inspection intervals during periods of severe conditions to secure that damaged carbon strips are detected and replaced before being put in operation. The wear can in severe conditions reduce the life of the strip by a factor 10 or more.

- Make sure that the fastening of the carbon to the carrier is temperature stable over a wide temperature range.

Some types of mountings of the carbon strip to the aluminium carrier can be sensitive to the temperature and temperatures well over 200 °C have been measured on the well cooled bottom surface of the carrier due to rime.

- Remove trees and branches that may get too close to the electrical wires in case of much snow.
- Remove ice formations in tunnels that risk hitting a passing pantograph. Cracks in tunnel ceilings shall be sealed to stop the water from leaking. It shall be noticed that these ice formations can grow very quickly in certain weather conditions.
- Use a quick-drop or emergency-drop function with a sensor normally mounted under the carbon strip (an air pressurised carbon strip). This reduces the number of pantograph and catenary break-downs and is a requirement in the high-speed rolling stock TSI²².
- Use integrated carbon horns instead of metal horns to reduce the risk for damaging the contact wire. The transition from metal to carbon can be a source for breakages as this is a weak spot.
- Power control systems in the train should not be sensitive to short power losses which may occur when there is a lot of rime on the contact wire.

Power losses due to rime that can cause some power control systems to go down and/or even activate the quick-drop function of the pantograph, may inhibit the running of the train.

2.9.2 PANTOGRAPH HEAD

The pantograph head is designed to give a constant or very slowly increasing force towards the overhead contact wire when the speed is raised up to the maximum speed. This shall also be the case when a vehicle is running in the opposite direction. Proposals:

- Make sure that the damping rate does not exceed limited values even in strong coldness.
- Movements in the head must not be blocked by ice as the current collection can be disturbed.
- Use preventive de-icing. Ice on airfoils can reduce their influence to control the up force and result in poor current collection as the high-speed wind effects are very big.
- Stationary pantograph detectors can be used to monitor the forces between the overhead wire and the pantograph and give an alarm if the forces exceed certain limits.

²² Lerouge, B & Alibert, B (2005). *Draft Revised HS RST TSI (main text)*. Brussels: AEIF 22.12.2005.

2.9.3 RAISING AND LOWERING OF THE PANTOGRAPH

The raising of a pantograph is in most cases done with the help of compressed air. The lowering follows by the weight of the pantograph when the air pressure is reduced.

In the region of Östergötland in southern Sweden all local trains were cancelled due to problems with the current collection one evening in January 2010. A combination of very cold but still humid air disturbed the system over head wire – pantograph by covering all components with ice in such a way that there was both a problem to get the needed electric power to the trains and a risk for damaging the pantographs and wires.

The following has been recommended for good operation during winter conditions:

- Air dryers must be used to avoid that damp air freezes in valves etc at low temperatures. Especially the lowering of the pantograph is of importance from an electrical safety aspect.

- Prevent snow and ice from gathering on the pantograph arms.

The high-speed wind effects are very big. Ice or snow on arms or aerofoils can change the up force and hence the current collection. Promising tests have been done with silicone on the arms to reduce the amount of snow and ice that normally gather there.

- The initial lifting force must be big enough to overcome the influence from snow and ice.

Wet snow or rain freezes on the arms when the pantograph is down. When the pantograph is to be risen the air pressure giving the force for the initial lift has to be big enough to do so.

2.9.4 PANTOGRAPHS ON TILTING VEHICLES

The following shall be kept in mind regarding pantographs on tilting vehicles:

- In areas where water cannot always be kept out, make sure that if the water freezes to ice, either the ice does not disturb the function, or arrange for heating where needed.
- The device that keeps the pantograph in the right position during the carbody tilting must be durable for winter conditions.
- Areas around moving parts must be designed to avoid snow packing. This is related both to the need for the movements but also to the need for sufficient insulation distances to the high voltage equipment.

2.10 ROLLING STOCK MAINTENANCE

During the winter months, maintenance has been described as twice as much work compared to the normal conditions at summer. For instance, the bogies and underframes are difficult to inspect and handle since these areas often are filled with snow and ice. The need of corrective maintenance is increased. Time consuming de-icing is often required.

In this section winter issues related to rolling stock maintenance are presented.

2.10.1 PREVENTIVE MEASURES

Trains need to be de-iced. In addition trains are usually more delayed during the winters. This results in a reduced time that the trains are available for effective maintenance. Together with the often poor workshop track capacity the tight work schedule may have an adverse effect on quality and availability. The situation sets off the importance of being well prepared:

- Take preventive measures in time.

Preventive measures must be taken before the winter season starts in order to obtain the best possible condition of the vehicle fleet. For example the heating, ventilation, steps, filters, pneumatic system etc need to be inspected and maintenance status improved as necessary.

- Reschedule preventive maintenance.

If possible, scheduled maintenance should be removed from the most critical winter season so that maintenance can focus on corrective actions and the additional time required for any type of maintenance actions.

2.10.2 VEHICLE FLEET

A big frequent problem in the winter time is the shortage of rolling stock. This is the result of an increased number of failures and the additional time required for the maintenance. Therefore:

- A larger fleet of vehicles is often needed wintertime or the planned service may have to be reduced.

2.10.3 DE-ICING

De-icing facilities are musts at wintertime – trains need to be cleared from snow and ice before maintenance can take place in the depots as well as to maintain proper performance in operation.

There are several problems related to de-icing:

- De-icing takes a long time; several hours per trainset are normal. This however depends on the train design, the ice and snow build up as well as the method of de-icing. If possible the time for de-icing needs to be shortened without increased risk for rolling stock damages.
- In general the de-icing capacity – seen to number and/or capacity of installations – is insufficient.
- The need of de-icing and de-icing capacity may vary over a country as well as by time. This means that vehicle circulations may need to be changed on a regular basis during the wintertime.
- Today there are no de-icing methods in operation that solves all problems:
 - De-icing with hot air takes long time. Eight hours for a train is not unusual in this case. The used air shall be dried if the hot air is blown into the electric motors or other electric equipment. Otherwise there is a risk for condensation when the train gets out into the cold outer air.
 - De-icing with cold water has been tried but is said to be unfavourable compared with hot water.
 - It is difficult to de-ice with normal hot water since this method may give problems later on. The slightest remaining water will most likely turn into ice and cause snow accumulation. Some actors even consider this way of de-icing as a failure.
 - De-icing by glycol is less energy consuming but the glycol dripping from the train has to be taken care of.
- De-icing is expensive. It requires a lot of space and energy. The operation itself is very costly.
- Trains must be designed with respect to de-icing and the de-icing method applied. In particular, if hot water is used cubicles and seals must be waterproof.
- If, after de-icing, a train is taken outside before it has dried up, the water that remains may freeze and the train then rapidly gathers more snow and ice during operation. This kind of incomplete de-icing can in some cases be worse than no de-icing at all.

This problem also concerns workshops in general. A train that spends time inside a workshop can hold water that will freeze quickly in the outside climate.
- Interviews indicate that during extra harsh circumstances high pressure de-icing with hot water in fire hoses is used. Mechanical means may be used. This is the practical emergency solution, no matter what the instructions say.

The de-icing problems are proposed to be solved by the following measures:

- Increase the number of de-icing installations or decrease the de-icing demand.

With present de-icing methods the capacity problem can be solved with increased number or size of de-icing plants. With more vehicles the de-icing demand could possibly be lowered.

Example: De-icing is needed once a week.

Assume a train operation is performed with 100 trainsets. Say that 90 of them are used daily 16 hours and five are used Mondays to Fridays in the peak-hours and get minor services in-between. Two trainsets are parked the whole week for repairs and the three remaining are being changed every day after one day of service. Each day 8 trainsets of the 90 can be changed-out, and over a week this means that $56 + 2 = 58$ trainsets out of the 100 have visited the workshop and have been de-iced in conjunction with that.

Remaining 42 trainsets will need de-icing the few hours during the night when they are not in service (six trainsets every night). With just one de-icing facility and a number of hours per trainset, this will not be enough. Thereto comes the time for transportation and shunting.

- Make sure there is no water or moisture left on the train before it is taken outside – of special importance is the brake system.

This solution is not difficult but requires time. It can be shortened through warm air drying.

- Design underframe parts with round surfaces where possible since they are easier to de-ice.

This design aspect has been discussed earlier in

Chapter 2.2 'Snow packing' in order to prevent accumulation of snow and ice.

- Use de-icing with propylene glycol.

De-icing is very much a question of transferring energy and for that glycol is much more efficient compared to air and water. Airlines have used propylene glycol for de-icing for over 20 years but it is not until now that the technology has been transferred to the railways in Scandinavia.



Figure 31. The old de-icing facility in Hagalund, Sweden.



Figure 32. De-icing with propylene glycol in Drammen, Norway.²³

In Hagalund, Sweden, there is a test installation (earlier there was also a test facility in Drammen, Norway). The facility is rather simple and does not demand a lot of space. In Figures 31 and 32 pictures of the installations in Hagalund and Drammen are shown.

The facility in Hagalund has a tank containing 16 000 litres of propylene glycol which is heated to +90°C. The liquid is applied to the train with a low pressure of approximately 0,6 bar through adjustable pipes. The idea is to de-ice the train outside while in motion. Between the rails are vessels that collect superfluous fluid which is reused. It takes about 40 seconds to de-ice a bogie and approximately 90 % of the fluid is reused. However, both these numbers depend on the bogie design and the ice and snow accumulation.

The location in Hagalund has in the last years been changed and the new site is shown in Figure 33 below.



Figure 33. The propylene glycol de-icing at Hagalund demonstrated in 2010 without any vehicle. It can be seen that a fairly low pressure is used for the de-icing. The nozzles are located both on the sides and in the middle between the tracks.

The propylene glycol that remains on the train is considered to have an anti-icing effect. Propylene glycol consists of round shaped molecules while snow molecules are sharp. This makes it hard for

²³ JM De-Icing system 2006. Information brochure.

snow to stick to propylene glycol. Interviewed experienced persons are convinced that the anti-ice effect works but the question is for how long. Propylene glycol is water soluble.

If propylene glycol de-icing would even work only half as well as expected, it has several benefits compared to conventional de-icing. It is much more cost and time efficient, enables anti-icing and can even be made portable. There have also been tests indicating that propylene glycol due to its viscosity will not push into nooks as easy as water does.

Propylene glycol is considered less harmful to the environment compared to ethylene glycol. It is classified as environmentally friendly and is water soluble. However, propylene glycol has a high biological oxygen demand. It can have harmful effects on foremost aquatic life and cause bad smells. Thus, it is of importance to control the propylene glycol waste.

Since 2010, there are four equipments in Norway in service during the wintertime. They are used both for de-icing and to get a long-term effect, and the information from the Norwegian railways is that they are very pleased with the facilities. Therefore trains are regularly – around once a week – treated with propylene glycol independent of the snow and ice situation. Figure 34 shows a tilting Class 73 on the summit of the Bergensbanen 1222 m above sea. Both the absence of snow on the train and in the bogies and the presence of snow elsewhere are striking.

Nevertheless the information from Sweden after the winters 2009-10 and 2010-11 is that the propylene de-icing is not sufficient and that other de-icing methods are preferred. The long-term effects however have shown promising results according these investigations.

The German-built high-speed Velaro trains for Russia are foreseen to be de-iced with propylene glycol.



Figure 34. A Class 73 approaches the Norwegian station Finse on Bergensbanen in January 2010. Notice the lack of snow and ice on the train.

2.11 TRAIN CONCEPTS

The majority of high speed trains in Scandinavia are electric multiple units (EMU:s) and not locomotives with coaches. Locomotives are in general simpler to design for winter conditions compared to EMU:s. They are normally heavier and more robust. Tilting trains are problematic from a winter perspective (for more detailed tilting problems see Chapter 2.3.3 'Tilting of the carbody').

High-speed trains, and especially EMU designs, have in general a bigger need for snow cleared tracks.

- EMU designs might require specific operational considerations.

In case of heavy snowfall it can be required to have a locomotive run ahead of EMU:s in order to clear the track. This is e.g. the situation in Finland during winters where a locomotive hauled train must run the line every day before the first high-speed train enters service²⁴. Also in Norway, locomotives are run for snow clearing ahead of high-speed multiple units during severe winter conditions.

When it comes to low floor designs it is very uncertain how this kind of rolling stock will do in winter conditions. Low floor often means that equipment needs to be placed on top of the roof where the equipment is exposed to snowfalls and snow smoke, which in worst case could contain gravel. Although the worst weather conditions regarding snow smoke are in the lower area, the roof area is not unaffected by the snow smoke; compare Figure 28.

2.12 WINTER TESTING

Winter testing of vehicles and components can be done either in reality during winter climate or in a climatic chamber. There are plusses and minuses with both. Figure 35 below shows a Velaro train in the climatic chamber in Vienna where it was tested prior to delivery to Russia.



Figure 35. Ongoing winter tests with a deep frozen Siemens Velaro train for Russia in Vienna climatic chamber.²⁵

In the 100 m long Vienna climatic wind tunnel different types of rain and snow can be simulated. The temperature can be lowered to below -40 °C. The wind speed can be up to 300 km/h but at lower temperatures the wind speed will be reduced. For instance in -20 °C the maximum wind speed is 200 km/h.

In a climatic chamber it can be specified what to test, how to test it and under which specified conditions. The problem is that is an artificial test with artificial snow. The ice and snow accumulations will also differ as the aerodynamics out on the lines are different.

On the other hand winter tests in reality will need a suitable winter climate during the test period with good testing possibilities in the regions where the right track conditions are to be found. This is why:

- A mixture of both test types will probably give the most valuable information both to the manufacturer and to the future train operator.

²⁴ (2006). *High-speed operation in winter conditions*. Helsinki: ANSERI Consultants Ltd.

²⁵ Siemens Velaro, Siemens AG

Independent of which method for the winter tests that is used, it is important that the tests are done during realistic and harsh conditions, see Chapter 2.1 'Worst weather conditions' regarding the vehicles and Chapter 3.1 'Worst weather conditions' regarding the infrastructure. Hence it is important to:

- Plan for a fairly long period of testing to increase the possibility to get the right weather conditions (real or artificial). Especially for tests done in the open air this is important. This also helps the test team to find those problems that not even were thought about.

2.13 AUTHORITY APPROVALS AND DEMANDS

An authority approval is not a guarantee that rolling stock related winter problems will not occur. This has of course to do with many things for example how the maintenance is carried out. The question is if there are problems that could be avoided through other authority demands and routines.

In the Swedish handbook for authority approvals there is nothing specific stated concerning winter conditions. The procedure is to perform winter tests that all new types of rolling stock must undergo and the supplier is responsible for the test. The authority may contribute to the test by discussing its contents and take decisions based on the test report.

The Swedish Rail Agency was changed in 2009 to the Swedish Transport Agency overlooking the whole transport sector. The following was stated in the Swedish Rail Agency's praxis for approval of rolling stock in winter conditions in 2006 (the quote has been translated into English):

"For locomotives and multiple units the snow and winter durability shall be shown with a winter test for at least four weeks in a snow covered area. Up to half of this time may be exchanged for a climate chamber test. Exceptions are given for locomotives and multiple units that have been in service in Norway for at least two winters.

For other rolling stock the snow and winter durability shall be shown through experiences of service during at least one winter month in a snow covered area.

Freight wagons and other rolling stock with tread brakes shall have brake pads approved by the Swedish Rail Agency. These approvals are based upon winter tests with brake pads in different materials. Freight wagons approved in other EU-countries with other types of brake pads are allowed to operate in the whole of Sweden independent of season according to TSI WAG 7.7.2.3.1.5 provided that the temperature demand is fulfilled."

(The Swedish Rail Agency 2006)

If the winter at the time of the test is considered to be too mild, the rolling stock will only be approved temporarily and further testing, when possible, will be required.

There are no standard procedures for how tests shall be carried out. As a consequence, an already approved vehicle may in fact face problems during more severe winters. This has happened and it caused severe problems leading to temporarily withdrawal of the rolling stock since the problem involved the brake system, see Chapter 2.4.1 'Disk brakes'. This means that:

- Authority approvals are not bullet proof and may need to be reviewed especially for higher speeds (above 200 km/h) since problems for this speed range is partially unknown.

During really harsh winters, temperatures down to -40 °C occur in northern Europe. Several interviews indicate that it is uncertain if electronic equipment such as computers and touch screens are able to start-up at these low temperatures. Design solutions must be used to ensure start-up and operation of a train at external temperatures down to -40 °C.

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According to the Swedish Rail Agency's praxis for rolling stock approvals the following is applied in Sweden as regards the outside temperature (the quote has been translated into English):

"Rolling stock approved for the whole of Sweden shall be specified for a temperature area Tn (-40°C – +35°C). Exceptions can be accepted for rolling stock specified for:

Lowest temperature	Allowed geographical area
-25°C:	Sweden except north of a line Kil – Frövi – Sala – Uppsala.
-30°C:	Sweden except north of a line Härnösand – Söderhamn – Bollnäs – Mora.
-35°C:	Sweden except north of a line Storlien – Östersund – Boden – Luleå.
-40°C:	All of Sweden."

(The Swedish Rail Agency 2006)

In the following Figure 36 these geographical temperature areas, for rolling stock, are shown. The demand has later been modified slightly – it is now the responsibility of the operator to make sure that the used vehicles are fit for purpose during all winter conditions in the operated areas. If not, the vehicles shall be parked until an approved higher temperature is reached.

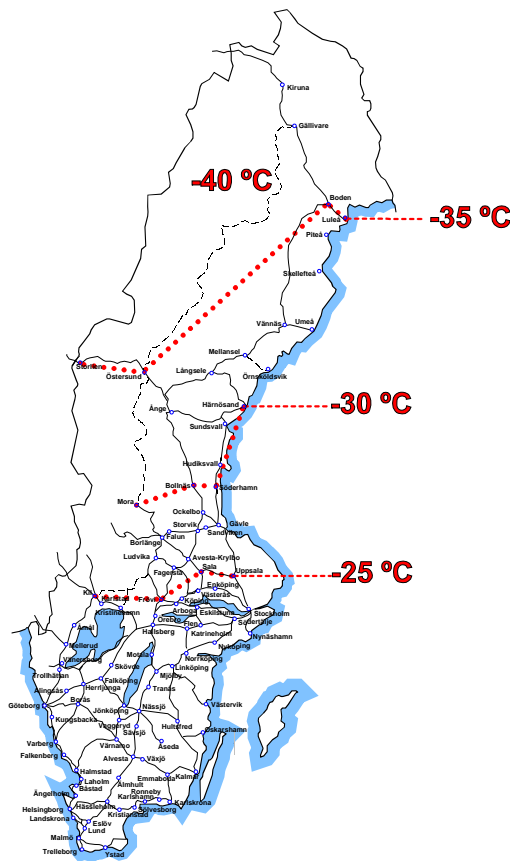


Figure 36. Geographical temperature areas for rolling stock as specified by the Swedish Rail Agency.

For the time being, there are three European temperature classes; T1: -25 to +40 °C, T2: -40 to +35 °C and T3: -25 to +45 °C. T1 is the basic level and it is up to the rolling stock buyer to decide what class should be applied. There are examples of rolling stock in Scandinavia today that only comply with the T1 standard. Together with the fact that many rolling stock winter problems can be avoided during the design phase the buyer plays a very important role in procurement and therefore:

- Authorities should ensure that there are proper design requirements and guidelines for winter performance of rolling stock to be used in Nordic winter operations.

3 INFRASTRUCTURE

This chapter on infrastructure winter challenges is structured in a similar way as the previous on rolling stock. It contains organizational issues as well as specific problems related to track and catenary. It starts by discussing the worst weather condition from the infrastructure perspective. All reported problems are considered to be more or less speed-dependent according to the definition in Chapter 1.5 'Definitions'.

In order to present the problem on a more general level this chapter opens with a Japanese quote with reference to Figure 37.

"Snow can seriously interfere with train operations. Trains may be stopped by snow accumulating on the tracks and turnouts, or by drifting snow or avalanches. Avalanches and snow drifts can derail a train, snow can damage rolling stock, snow adhering to rolling stock may fall off while the train is in motion and cause an accident, and railway structures may collapse under the weight of snow.

A number of structures can be erected to prevent these and other problems. The snow can also be removed before it becomes a serious nuisance using rotary snowplows or Russel (pushing) snowplows. In addition, winter schedules can be devised to permit the alternate use of snowplows and trains on the same track. Train operation controls can be implemented on a phased basis, depending on the amount of snow on the tracks and snow removal conditions.

Avalanche risk is evaluated from the air using helicopters, and on the ground during patrols. When an avalanche is anticipated, especially during the snowmelt season, special surveillance measures are taken to protect rail operations. A different problem is seen in tunnels—freezing of leaking water. To prevent this, structures equipped with thermal insulators are being developed and installed.

The following measures are taken to protect Shinkansen from snow damage. In the case of the Tokaido Shinkansen line, sprinklers spray water on ballasted track during snowfalls. This makes snow wet, otherwise it would fly up when trains speed by, and prevents snow from adhering to rolling stock.

The Tohoku and Joetsu Shinkansen lines run through areas subject to greater snowfalls. Ballasted track sections are shorter there, and rolling stock is designed to inhibit snow adherence. Viaducts on the Tohoku Shinkansen line have been constructed to withstand snow depth equivalent to the annual return in a 10-year period. On the Joetsu Shinkansen line, water sprinklers melt snow on track sections in the plains and on long, tunnel-free sections in mountainous areas. Snow sheds and snow shelters have been constructed over shorter sections between tunnels."

(Noguchi & Fuji 2000)

Although the measures taken in Japan not always are appropriate for Swedish or Northern European conditions, it is obvious that Japanese railways dedicate big sums to solve different winter-related problems and try to tackle them seriously.

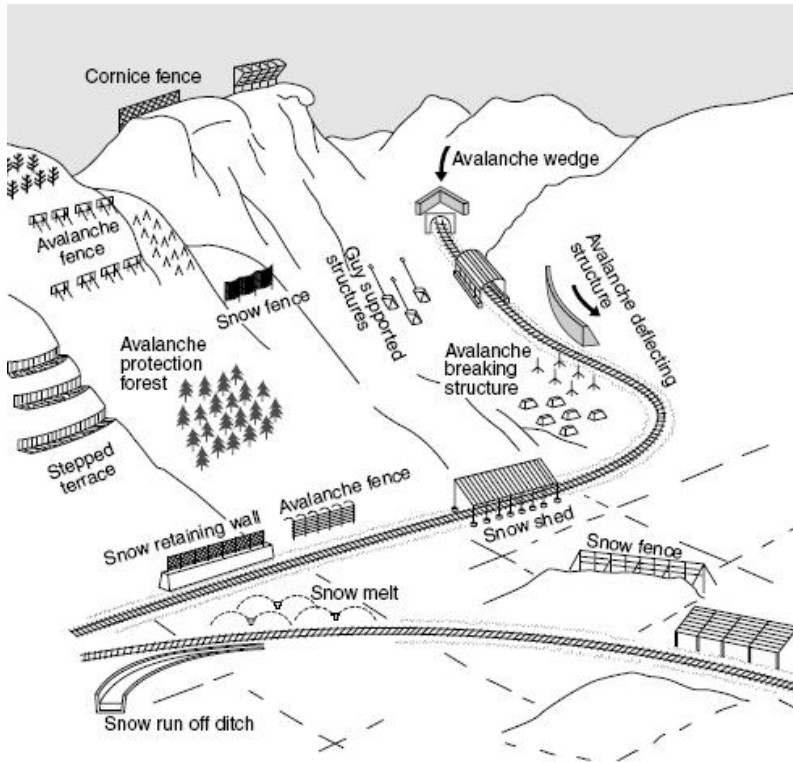


Figure 37. Japanese snow protection system in the infrastructure²⁶.

3.1 WORST WEATHER CONDITIONS

As for the rolling stock it is hard to make out a general conclusion about the worst weather for the infrastructure. The most common and most severe problems differ from year to year. The track and the overhead catenary system are affected differently by the various weather conditions. In this case it is also hard to distinguish between track and catenary winter problems when it comes to which are the most crucial to the operation on the line.

Considering the track there are two situations that cause most harm to the railway operations. These are:

- 1) Heavy snowfall
- 2) Snow in combination with wind.

The extreme snowfalls are really hard to handle and especially at stations where there are normally no good places to keep the removed snow. At these yards there are also switches that may require manual snow clearing which is a time consuming procedure. Wind can complicate the situation further by spreading not properly cleared snow over the station area and its switches.

Wind and snow is a devastating combination for switches. This as snow is being transported horizontally and ends up in switches between the rail and the switch's tongue. The switch is then put out of function.

Even for the catenary snow can be harmful if it causes trees and branches to fall into the free space and then damage either the contact wire or the pantograph. The overhead wire is a vulnerable system and in general weather influences brings the largest problems. Damage or malfunction of the pantograph often causes tear down of the overhead wire.

²⁶ Noguchi, Tatsuo & Fujii, Toshishige (2000). Minimizing the Effect of Natural Disasters, *Japan Railway & Transport Review*, No. 23, pp. 52-59.

There are three kinds of unfavourable conditions for the catenary:

- 1) The first is rime on the contact wire, which increases with lowered temperatures.
- 2) The second concerns the forming of ice on the pantograph. Ice on the overhead wire also occurs, but is rare. It is especially wet snow in the temperatures around zero that easily turns into ice. Ice is also created very fast on the pantograph at the occurrence of fog and minus degrees, especially at high speeds due to the cooling effect.
- 3) The third is related to the temperature. The increased stiffness, both regarding the pantograph and the catenary, at low or very low temperatures increases the risk for damages.

3.2 ORGANIZATION

In order to cope with the problems that may arise during winter, the infrastructure managers set up winter preparedness plans. The plans are discussed with other involved parties such as the operators. An emergency preparedness plan describes how to handle and limit disturbances that may arise due to weather during wintertime. The plan also defines organisation and prioritized tracks and stations on each route etc. In addition to these preparations, infrastructure managers prepare for winter through several other measures. Resources such as machines, personnel, subcontractors etc. are prepared. Snow covers are assembled in switches, the heat in the switches is checked and the tracks and areas close by are cleared. However, despite all the preparatory work there are several problems related to the infrastructure.

It is sometimes argued that the origin of the setbacks is due to lack of communication between the infrastructure managers and operators for instance when it comes to which tracks to be prioritized. The emergency preparedness plans are also criticized for not being enough proactive. Therefore:

- It is important that emergency plans only are used as emergency plans at severe conditions and not as the normal way to handle every snow and winter problem.

A large problem that has come to light throughout this investigation is the fact that maintenance activities such as clearing the track from snow somewhat lack comprehensive coordination. This kind of responsibility is divided among geographical areas, organizations and people, meaning that optimisation takes place from rather small regional perspectives. That is why:

- Winter demands comprehensive coordination – an organization that takes a general approach on winter issues. With many different operators on nowadays tracks it is important that the track owner, i.e. each government in the European countries, at least regarding the tracks for higher speeds, takes the responsibility for an overall winter organization including the necessary equipment.

People working with the daily infrastructure operation have sometimes problems to receive the proper information at the right time. Too often is the dialog with the traffic control not good enough concerning preventive measures. In order to be more proactive:

- Snow removal staffs need information about the operation conditions more frequent and in time.

Clearing the tracks from snow is a dangerous work and fatal accidents have happened. The work is done in or nearby one track and trains run on the next track close to the workers. In the wintertime often the passing trains can hardly be heard due to the reduced sound level because of the snow. For this reason it is vital that:

- The safety regulations are updated and consider the high-speed operations with fast and quiet passing trains. The staff working with snow clearance ought to be given a rehearsal regarding safety for working in or nearby the track at the beginning of each winter period. This is most important in modern operations with a lot of contractors and sub-contractors performing the work. These people do not necessary have the long experience as older railwaymen had.

The quality of the train services depend heavily on the infrastructure. It can be argued as somewhat peculiar that mainly operators and their customers benefit from an infrastructure in good condition. With the present quality system, infrastructure managers are without proper incentives and maintenance personnel can in practice only receive criticism. It is on the other hand not fair that operators should carry all the risks by themselves. For that reason it has been argued that:

- New terms for infrastructure quality, containing both penalties and bonuses, should be considered.

In the eyes of the public, winter appears to strike as a surprise to all train services. More or less the same problems occur every year. To partly overcome this problem it has been proposed to produce:

- Better information on weather forecasts.

Infrastructure managers need access to better weather forecasts and preferable weather prognosis adjusted to the railway. Today there are special systems regarding for instance snow, measuring and forecasting ice on the overhead wire, rail temperature, wind etc. Through these geographical information systems the preventive maintenance actions of the infrastructure could be arranged quicker and better.

3.3 TRACK

As well as for the rolling stock an excessive amount of extra work must normally be put on the maintenance of the track at winter. There are a lot of winter problems that are being generated during operation at bad infrastructure conditions. For instance, a poor track status can result in rolling stock damages which subsequently may harm the track. More inspections of the track are therefore required during wintertime.

3.3.1 SNOW CLEARING OF THE LINES

The clearing of snow is a large challenge wintertime, primary as it can both be difficult to perform and since there can be severe consequences in train operations if the snow clearing is not properly done.

To clear the track from snow is many times easier said than done. The action takes time to carry out and depends to a large extent on the access to the track. Often snow clearing can only take place during the night time when there is a reduction in the traffic. Otherwise, snow clearing can cause train delays and even cancellations. Snow clearing can also be hard to plan since it may depend on other more acute track maintenance demands.

In February 2009, the morning train No 62 ran into an avalanche at Storekleven east of Myrdal station on the Bergensbanen in Norway and derailed, see Figures 38 and 39. Train No 62 consisted of two train units Class 73 coupled together.



Figure 38. The train derailed with two cars between two over-head wire poles without striking them. The pantograph, located on the third car of the four car set, was in contact with the over-head wire also after the derailment. The second train unit has been moved backwards before the photo was taken.²⁷

²⁷ (2008) Statens Havarikommisjon for transport. *Rapport om avsporing etter sammenstøt med snøskred ved Storekleven på Bergensbanen 21. februar 2007.*



Figure 39. The couplings did not break and the train unit came to a halt in one piece with just the two first cars derailed.²⁸

The first two cars of the train derailed. The train was carrying 130 passengers and a crew of 4, but no one was seriously injured. The train ran off the tracks between two poles for the overhead wires without damaging them. Consequently, the train had continuous power supply, which meant that light and heating were intact. On the day of the accident, the train also had an extra Class 73 four-car unit. This was later used to evacuate the passengers from the avalanche site. The passengers were then brought by railway to Myrdal station and transported further on from there.

The investigation showed that snow mass had become dislodged and fallen onto the track²⁹. The avalanche consisted of very compact snow masses. When the train ran into the snow it was forced out to the right, as it was compressing the snow against the side of the mountain to the left, and it is likely that snow simultaneously dislodged the grip of the wheels of the first bogie. The train climbed over the track, derailed, and skidded down a steep slope before burying itself and coming to rest in the snow masses.

The track had not undergone snow clearing immediately before train No. 62, although a snow clearing train had left Myrdal station 2 hours and 15 minutes before the train, in order to carry out snow clearing and inspection of the line. Both the normal snow clearing units (Beilhack, rotating snow throwers) were out of service on that particular day.

The Norwegian Accident Investigation Board made three overall recommendations:

1. Better protection of sections of mountain railway lines which are vulnerable to avalanches.
2. Better weather forecast services for mountain railway lines.
3. Better communication and procedures between the Norwegian National Rail Administration and their machinery centre with regard to access to snow-clearing equipment.

It has been reported from Japan that there is a warning system for avalanches. This ought to be used on all lines where there is an increased risk for avalanches, such as on Bergensbanen.

The day after the accident before the line had opened, the wind totally covered the line with snow as can be seen in Figure 40.

A separate investigation of the accident indicates that there would have been a great risk for derailment also for a locomotive-hauled train, although a locomotive is equipped with a standard Norwegian snow plough and has a higher axle load on the front axles. The avalanche was three or four meters high on the mountain side of the track and just around a meter on the valley side. This

²⁸ Ibid.

²⁹ Ibid.

together with the compressed snow on the left side would probably have lifted a locomotive off the track to the right as well.

It has been reported that DNV (Det Norske Veritas) has made a report regarding derailment risks with tilting EMU trains in deep snow on the Bergensbanen. From that report it seems that DNV were not convinced that the Class 73 not showed bigger risks for a derailment in deep snow than for instance a locomotive-hauled train³⁰.



Figure 40. The line close to the place for the accident covered with snowdrift the day after the accident.³¹

If the snow clearing is not performed in a proper way there is a risk of the following consequences:

- Derailments.
Both ice and snow in the track may cause a train to derail. Snowdrifts as well as ice that reach high up on the rails are considered dangerous, see Figures 38 - 40.
Ice can be common in tracks that are located near watercourses and in tunnels.
- Trains get caught and/or lose time.
A train's running resistance increases with the snow masses in the track which affects the running time. Sometimes these masses can cause a train to get stuck. Even if the track has been cleared from snow the space next to the track can be full so that the snow infringe on the free space.

In February 2010 an EMU got stuck in a cutting on the line Malmö – Simrishamn in southern Sweden, Figure 41. The passengers had to be evacuated and the line was blocked nearly a week until the trainset could be removed.

³⁰ Lokomotivmans Tidende nr 11/12-2008. Avsporingen i Storekleven: Havarikommisjonens rapport

³¹ (2008) Statens Havarikommisjon for transport. *Rapport om avsporing etter sammenstøt med snøskred ved Storekleven på Bergensbanen 21. februar 2007.*



Figure 41. With help from the army the passengers were evacuated from this EMU Class X11 that got stuck between Tomelilla and Simrishamn in the far south of Sweden³². Class X11 is a two car unit with 1280 kW and a total mass of 100 tonnes.

In this part of Sweden, a harsh windy winter with a lot of snow often creates problems with snow drift. Further north where this kind of climate is more common, different kinds of protections, such as wooden fences, are mounted especially at places where there is a big risk for problems with snow drift. No such protections can be seen in Figure 41.

One of the first days after the train got stuck it was tried unsuccessfully to pull it loose with another EMU. Instead the permanent way staff first had to manually and with machines remove the snow (Figure 41) to reduce the resistance before the units could be moved. Five days after getting stuck in the cutting the trainset was towed away.

Other problems that can occur when the clearing is not properly done:

- Snow penetrates into the trains and cause difficulties, see Chapter 2.5.2 'Doors and steps' and Chapter 2.8 'Electric traction systems'.
- Damaged rolling stock equipment.

Patches and lumps of ice that hit the train may damage rolling stock equipment. Collected ice blocks nearby the tracks or on the tracks – which have dropped down from trains, tunnels or from bridges – can destroy parts of the train, e.g. windows, underframe, cables and various equipment. The higher the speed, the higher is the possibility of damages by flying ice pieces.

- Non-functioning switches.

Switches are very sensitive infrastructure components that in some situations need almost constant clearing, see following Chapter 3.4 'Switches'.

In order to assist snow clearing and avoid snow gatherings on the track, a number of measures have been suggested:

- Create space for snow.

It is needed to have areas next to the track available for snow storage. Otherwise snow is consequently being packed along the track and may sooner or later get into the free space. There are examples of trains getting stuck due to snow pressed against walls in tunnels.

When the line has been ploughed and there is still more snow to come, it is important to push the snow further to the side to create sufficient space for the coming snow. On the Class Tb locomotive in Figure 42 only the wing plough on the far side is being used to push the snow away. The line itself is already cleared.

³² Ystads Allehanda, February 15 2010. *Tåget sitter fast sedan i fredags.*



Figure 42. A Swedish (Bo)' (Bo)' Class DLL (ex Class Tb) clears the trackside snow on an electrified line³³.

- Use avalanche warning systems on line sections where there is a risk for avalanches. An avalanche consists of packed snow and is always a great derailment risk, see Figure 38.

The Railway Technical Research Institute in Japan has developed an avalanche detection and warning system for railway tracks. Prototype experiments have shown that the system is accurate to detect the occurrence of an avalanche and also to evaluate their sizes. This will then result in an alarm when required.³⁴

- Cuttings need to be designed in such way that they do not get blocked by snow.

A long cutting is an example of an area that needs space for snow. This is also a Japanese learning according to Figure 43, which shows that a wider space is needed for cuttings located in snow affected areas. A design like this that respects winter also eases ploughing.

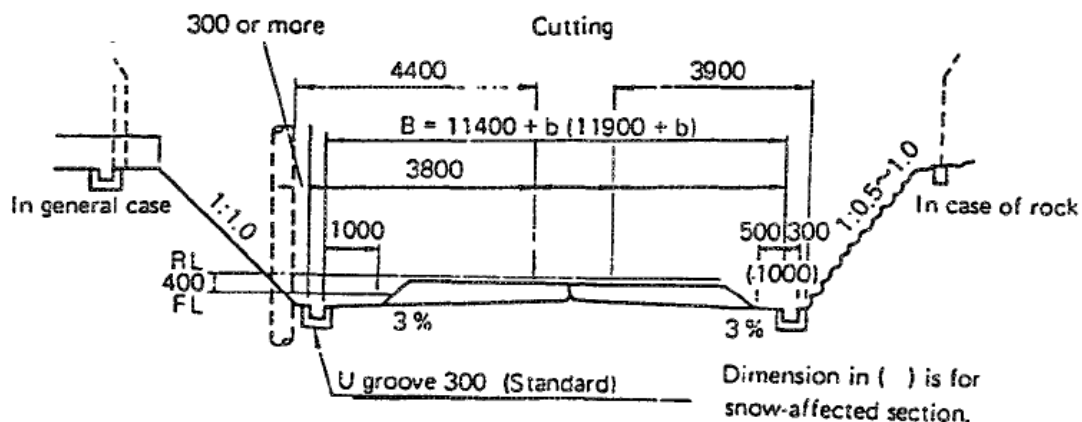


Figure 43. Japanese infrastructure construction standards with respect to winter³⁵.

When the amounts of snow are enormous even a wide cutting is not wide enough. There will be problems anyway which can be seen in Figure 44 taken more than 100 years ago in the U.S.A.

³³ SR Östergötland, February 24 2010. *Järnvägens snöplogslök skrotas*.

³⁴ Noguchi, Tatsuo & Fujii, Toshishige (2000). *Minimizing the Effect of Natural Disasters*, *Japan Railway & Transport Review*, No. 23, pp. 52-59.

³⁵ Taniguchi, Mamoru (1992). *High Speed Rail in Japan: A Review and Evaluation of the Shinkansen Train*. California: The University of California Transportation Center, Working Paper UCTC No. 103



Figure 44. Snow drift blocking the railway line of Chicago, Milwaukee and St. Paul Railway. The photo was taken on March 29, 1881³⁶.

In Figure 45 it can be seen that we never learn from the history. In December 2010 a Class X11 EMU trainset again got stuck in a cutting on the line Malmö – Simrishamn in the far south of Sweden. The passengers had to be evacuated and the line was blocked nearly a week before the trainset could be removed. Compare Figure 41 from the previous winter when a similar train got stuck on the same railway line some 50 km further east.



Figure 45. Two EMU:s got stuck on the line between Malmö and Ystad at Balkåkra the day before Christmas Eve 2010³⁷.

The cutting is not deep, but filled with snow it is covered up to the windows of the EMU. To release it, six snow melting heaters and two excavators had to be used together with a lot of manual shovelling. The train was towed away after the Christmas holidays.

Further steps to take that can improve the winter operation:

- Dedicate tracks to frequent high-speed services.

³⁶ http://en.wikipedia.org/wiki/File:Train_stuck_in_snow.jpg

³⁷ Kvällsposten 28 december 2010. *Pågatåg fast i snön sedan lillejulafton.*

A frequent high-speed train service tends to clear the line by itself and keeps it clean at least before to much snow has fallen. This may imply that snow covers are not needed in switches on lines dedicated to high-speed services.

- Make sure that the track is properly drained.

During the winter there are quite often periods when the temperature rises above zero, which means that some snow will melt. If the track is well drained most water will disappear – otherwise it will stay and freeze when the temperature drops and, for instance, block switches.

- Snow fences may be required at some locations with specific risk of snow drifts, especially close to cuttings.

In this investigation a few other solutions have been proposed, but these are not considered quite appropriate from either a winter or a high-speed perspective in the Nordic countries. Therefore these measures are only briefly mentioned:

- The track can be raised above the ground so that snow blows away more easily.
- Snow can be melted by water. Figures 46 and 47 give examples of designs of this kind of system. See also Chapter 3.3.5 'Snow removal in yards'.

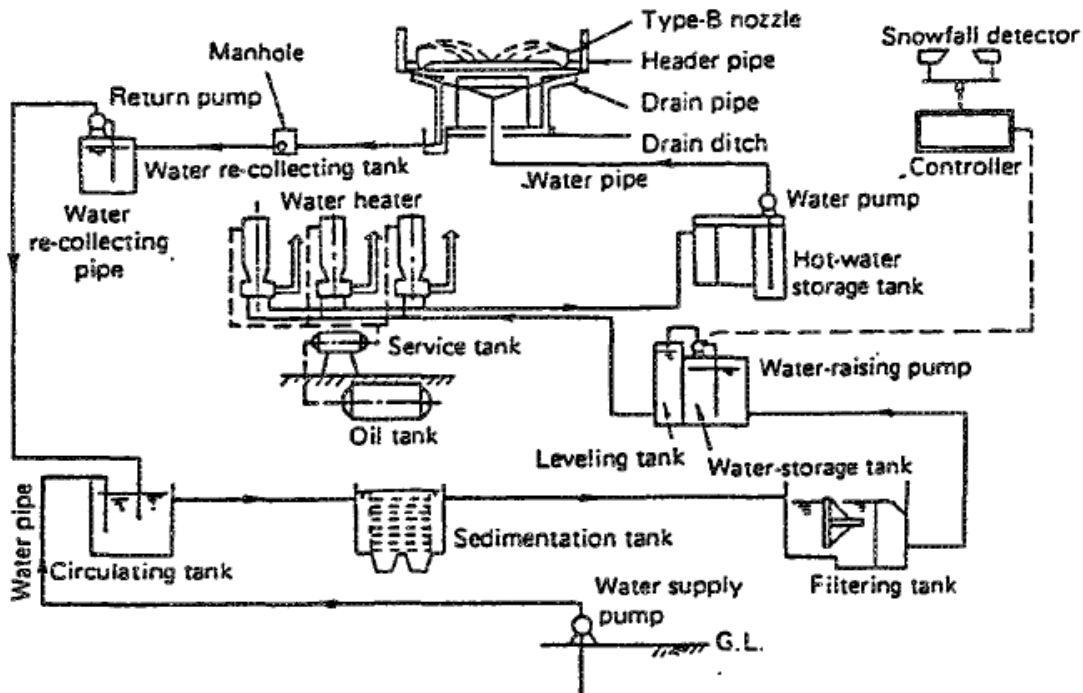


Figure 46. Outline of a Japanese water sprinkler snow melting system³⁸.

³⁸ Taniguchi, Mamoru (1992). *High Speed Rail in Japan: A Review and Evaluation of the Shinkansen Train*. California: The University of California Transportation Center, Working Paper UCTC No. 103.



Figure 47. A Japanese water sprinkler system in practice on East Japan Railway Company. Notice the amount of snow on the catenary and the ground free from snow³⁹.

3.3.2 SNOW CLEARING OF THE YARDS

Snow removal in bigger yards is often a problem as there usually is a lack of space to put the snow, see Figure 52 in Chapter 3.4 'Switches'. On marshalling yards the snow is often swept to the side which is enough when the amounts of snow are small. But with more snow it has to be loaded on wagons and transported away somewhere where it can be dumped. If the snow must be transported away there is trouble with the disposal since the snow is considered to be contaminated.

The snow removal plans for yards must also include the responsibilities of all the different actors that are involved with the rail operation in a certain yard. In the winter time the demand for repairs and wheel turnings normally increase. It is therefore of importance also to keep other tracks than the most important ones open during the long and cold winter. There must be free tracks for parking of vehicles waiting for repair or wheel turning without blocking other vehicles entering or leaving workshops.

The winter 2009/10 was a disaster for the main Swedish marshalling yard Hallsberg. When it was realised that the snow had to be transported away, there was no available equipment that could be used on the yard, which was newly equipped with a new track brake system, see Figure 48. Neither tractors nor rail bound vehicles could be used. The end of the story was that the yard was closed for nearly two weeks which resulted in freight trains being parked and waiting all over the area. These parked trains affected the whole railway system by blocking all sidings, and passing passenger trains and high-speed trains were also delayed.

The winter 2010/11 was instead a disaster to the Malmö marshalling yard in south Sweden. It was closed for nearly a week and this influenced all trains in the southern part of Sweden with delays and cancellations as a result. The sub-contractor responsible for the removal of snow has thereafter declared that "...the snow fall in Malmö around Christmas and New Year was so intense that the amount of snow was more than could be transported away during the hours that we had access to the tracks."⁴⁰ How this could be the answer to "why closed for a week" is still an open question.

³⁹ (2011) Akihiro Nakahata Countermeasures for snow disasters of JR East.

⁴⁰ Svenska Dagbladet 12 april 2011. *Storbråk om punktlighet i snökaoset*. Swedish newspaper article translated to English.



Figure 48. The new track brake system at Hallsberg marshalling yard before the snow fall⁴¹.

The described cases could be said to be the result of inappropriate planning not anticipating severe winter climate could possibly occur.

A Swedish company has developed a method to remove snow from yards by sucking it up and at the same time melting it with warm water (50 °C) and store it in a tank wagon, see Figure 49. This reduces the volume to a tenth of the volume of the snow. The water can thereafter be emptied as surface water. This type of equipment has been used at the central stations in Stockholm and Oslo.



Figure 49. Equipment that sucks the snow in and at the same time melts it with warm water. The water is then sucked further to a container before it is emptied as surface water. The operator can manoeuvre the equipment from a platform on the side of the vehicle for better visibility⁴².

From the given examples it is obvious that:

- There is a need for plans how all parties in a station or a yard shall contribute to make the train operation as unaffected of the snow as possible.
- To have equipment and personnel ready for the winter will cost money. In countries with snow every normal year, this is something that has to be paid for. The public sector cannot accept to have an infrastructure that collapses each time there is a heavy snow fall or to have too many vehicles to malfunction.

3.3.3 SNOW CLEARING IN TUNNELS

Tunnels can cause difficulties at winter. This has to do with both the narrow space which is often the situation in tunnels and the tunnel climate. It is often warmer inside tunnels causing snow and ice to

⁴¹ (2006) Banverket Handbok BRÖH 313.0001. *Anläggningsbeskrivning Hallsbergs rangerbangård.*

⁴² Railcarenytt 2004. *Varmvatten bot mot snökaos*

fall off trains. Together with various water leaks the snow and ice that are being dragged inside by trains, make the forming of ice accumulations very common. The ice may cause a train to derail, especially if it builds up between the rails towards the rail head. Then the wheel flanges risk to be lifted up with a derailment as a probable result.

Another risk is to collide with icicles which for example could damage the pantograph.

Longer tunnels, more than a couple of km, are significantly warmer in the middle than at the entrances. In addition the warm air in the tunnel is very humid. These temperature changes as well as the changes in humidity can be problematic to passing trains, see example from Eurotunnel in Chapter 2.8.1 'Motors and cooling systems'.

Winter problems in tunnels are today managed by:

- Clearing tunnels from ice and snow – both along the track and at the overhead wire.
- Sealing leaks in tunnel ceilings and walls to reduce the problems with water and moisture that freezes.

3.3.4 FROST IN THE GROUND

Frost in the ground can either move the track or cause other track geometry irregularities which influence a train's running dynamics. Derailments due to a frozen ground on main line sections are on the other hand very unusual. This perhaps as the process where frost in the ground causes track irregularities is very slow and the problem can be discovered before the situation becomes critical.

High-speed tracks normally consist of better infrastructure with a well drained ground and therefore the problems with frost in the ground are rather rare but when trains run at very high speeds, just small track alignment faults will create big forces. The running properties are affected and normally get worse with increased speed. The track movements will worsen the ride quality, increase the track forces and in worst cases, although unlikely, cause a derailment.

Problems with frost in the ground and track movements caused thereby can be managed by:

- Regular checks of the line.
- Sensors or reduced speeds where there is an increased risk for track movements.

3.3.5 TRACK STIFFNESS

To keep the track stiffness within the specified limits is of great importance for the running performances. The following winter problems have been identified in this study:

- The track gets stiffer when the embankment is frozen and the increased track stiffness may cause increased wheel-rail forces. It may affect train and track maintenance as well as the passenger comfort. The situation may become worse at increased train speeds⁴³.
- In particular older rails may become more brittle when it is very cold and accordingly more sensitive to damages from for instance wheel flats. Smaller wheel flats affect the bearings which can result in hot bearings and in the end possibly axle failures.
- The friction on the rail increases with reduced humidity, which normally is the case during the winter season. Hence if grease is added to the rails also in the winter time it reduces the wheel and rail wear.

To reduce the risks for rail breakages it is wise to have:

- Wheel flat and hot box detectors checked before the winter period.

3.3.6 TRACK CLEARANCE EQUIPMENT

Different track clearance rolling stock has already partly been described, see Chapter 3.3.1 'Snow clearing of the lines' and 3.3.2 'Snow clearing of the yards'.

⁴³ SJ MTL 130/160 LR 8412-10e Spårkrafter gångegenskaper Rc3 och LR 8501-10e Spårkrafter, gångegenskaper, tøjning

High-speed train operation in winter climate

On Bergensbanen in Norway big rotary snow throwers are used, see Figures 50 and 51, which can throw the snow some 50 meters away. To be able to run in the opposite direction the upper part of the vehicle can be turned 180 degrees. When not working, the self propelled snow thrower can run with a maximum speed of 90 km/h.



Figure 50. Demonstration of a 1440 hp rotary Beilhack snow thrower at Finse in January 2010 on Bergensbanen.



Figure 51. The Beilhack machinery can be turned for operation in both directions.

In Sweden most of the 10 + 20 diesel locomotives Classes Tb and Tc, which were bought after the problematic winters during the sixties (see Figure 42) now have been withdrawn or scrapped. Still the remaining fleet represent the major heavier snow clearance equipment in Sweden although a great number of lighter vehicles have been bought with smaller front ploughs rotaries or brushes but most often without side wing ploughs. The two winters 2009/10 and 2010/11 have shown that this has not been sufficient.

3.4 SWITCHES

Problems due to malfunctioning switches are the most common reasons for infrastructure disturbances during the winter period. In the Nordic countries special snow protections have been mounted in switches to reduce the amount of snow that gathers and to keep the area between the two tongues clear. Unfortunately, the protection cannot fully cover the movable parts.

With higher train speeds it has been obvious that the snow protections do not function properly. They break to pieces and/or parts come loose. This is due to both the ice that fall off the train and hit the covers as well as the strong air streams under the passing train.

The number of covers in use has been reduced in recent years especially on lines with high speeds. This action is also motivated by the fact that trains running at higher speeds clear the track from snow better as long as the amounts of snow are reasonable.

Winter problems with switches can be categorised as follows:

- Problems related to snowfall, snowdrift etc.
- Frozen parts in the mechanism
- Blocked movements
- Maintenance

3.4.1 PROBLEMS RELATED TO SNOWFALL, SNOWDRIFT ETC.

In the Nordic countries, all major switches are electrically heated to melt the snow that gathers along the two rails. In long high-speed switches, as much as 40 kW can be needed for heating the main rails for the length of the two tongues and the movable crossing.

In order to reduce the problems with the switches a number of preventive measures have been proposed:

- Make sure the mounted heating equipment is optimized and functioning.

It must be considered how many kilowatts that shall be installed in a switch and the costs for the energy compared to the need of having it functioning regardless of the weather. An alternative can be to allocate maintenance people to critical switches during times of operation. However this means blocking the line as long as manual work is being done in the track.

- Optimize the on and off periods for the heating

The heating shall only be turned on when needed, automatically or manually. Having it on all the time results not only in high energy costs but also that there will be too much water that will freeze in the ballast and cause problems.

Together with the weather forecast and local weather measurements the best automatic switching-on and off is accomplished. On manned stations there shall be a possibility for the station staff to activate the electric heating of the switches as desired. An example of when such an extra need occurs is when there are cross winds.

Only the heating itself cannot clear the switch in very heavy snowfall. Manual or motorised brushing will also be needed. It is recommended to clear the whole switch from snow as well as some 20 m on both sides of it.

Figure 52 shows Norrköping main line station area in Sweden on the 29th of December 2010. There was a heavy snowfall over the area around Christmas but still nearly a week later the station area is not cleared.

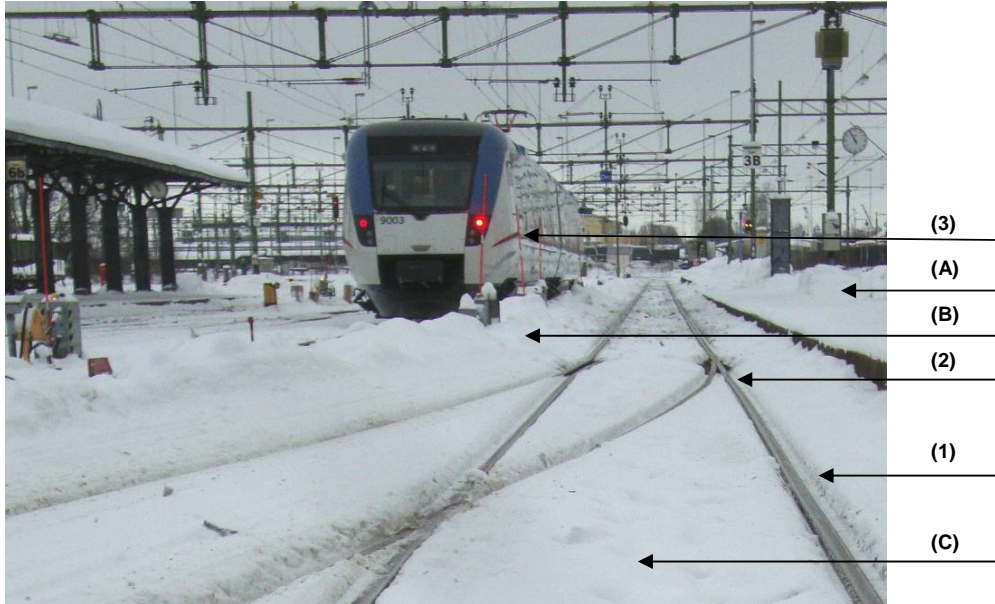


Figure 52. Norrköping central station some 180 km southwest of Stockholm. The station area is filled with snow on the platforms (A), between the tracks (B) and in the tracks (C). Top of rail is far below the snow (1). If another snowfall comes there are no more places to put the snow. The switch is not cleared – only the electric heating has been on, which can be seen at the tongues (2). The red sticks show where stationary 1000 V can be found for a parked train (3).

Figure 52 focuses on one major reason for winter problems regarding the infrastructure. It is essential to be proactive and take every chance to prepare for the next snowfall instead of saving short-term money by doing nothing. When it comes to reliable railway operation in winter climate, proactive measures form the base, although there has to be preparedness plans for other measures as well.

- Make plans how to operate the line with just a small number of the switches in function.
During snowfall it is sometimes better to use a smaller number of switches more frequent and let the rest be untouched. The latter shall then normally lay in the mainly used direction.
- Mount some type of stopper along critical switches for the wind borne snow such as snow fences or some type of spoilers. Below these installations are detailed.

SNOW FENCES

Along line sections with frequent harsh snow conditions often snow fences or snow sheds are mounted, compare Figure 37. This can also be done at places where there are important switches.

RUBBER SPOILERS

Tests have been made with a rubber spoiler along the main rail for the length of the tongue, see Figure 53. The spoiler is mounted outside the rails to a level some 100 mm above top of rail, which can be accepted as the material is rubber.

The spoiler is supposed to lift the snowdrift so that snow will not fall between the tongue and the main rail. The protection does probably only work for cross-winds. There is also a cover under the spoiler to insulate the heated rail on one side for the cooling effect from cross-winds. The evaluation is yet not completed.



Rubber spoiler

Figure 53. Skutskär. A main line switch with a rubber spoiler as well as a cover outside the rails. Notice that there are double motors for altering the switch.⁴⁴

V-FORMED SPOILER

Information has been received that a V-formed spoiler has been used in Finland in front of switches as a spoiler to reduce the amount of snow that gathers there. More details of this as well as eventual effects are not known at present.

BRUSH SPOILERS

Tests have been made with long brushes along the outside of the main rail, see Figure 54. As far as known the effects are the same as with the rubber spoiler. The advantage by using double brushes is that the lower brush isolates the heated rail on one side and reduces the cooling effect from cross-winds. The height of the double brush is some 300 mm.

The tests are performed in Sweden with help of a brush manufacturer. The results are not known today.



Figure 54. Detail of a brush spoiler is seen to the left. To the right the mounting outside the main rails in a switch is shown.⁴⁵

⁴⁴ Photo from Banverket in report 'High-Speed Train Operation in Winter Climate' (2006)

⁴⁵ (2006)Photo from Osborne International

3.4.2 FROZEN PARTS IN THE MECHANISM

The mechanism of an electrically driven switch consists of the switch motor, the interlocking, the manoeuvring rods connected to the tongues and the contacts for the positioning check. All these mechanical movements must function. Otherwise the traffic control will not know if and how the switch has been altered. Therefore:

- The motor seals must be fit for purpose. Water must not come into the motor mechanics.
- The drainage around the motor and the rods must function all year around.

The rods used for manoeuvring the tongues or the switch motor tend to freeze when melting snow gathers and the drainage around the rods is not sufficient. This can be the situation when the temperature often changes from plus to minus. Then the ground cannot take care of more water, which stays and thereafter freezes.

There have been discussions about the possibilities to heat the ballast around the rods and the motor where the problem often occurs.

- The positioning contacts must be hindered to freeze as well as they must function also in severe winter conditions.

If the positioning contacts in the switch freeze, the position of the tongues cannot be checked and controlled, see Figure 55. If the switch position is not known, the Swedish rule is that it must be closely examined by the train driver and speed is restricted to 10 km/h.



Figure 55. A switch with rubber spoiler and covers outside the main rails. The contacts for positioning control of the tongue can be seen next to the far tongue.⁴⁶

3.4.3 BLOCKED MOVEMENTS

The movement of the tongues can be blocked for various reasons. The most common reason is snow and ice falling off a passing train when running over a switch. Just at the crossing normally the trains rattle causing snow and ice to fall down, not seldom between the tongue and the main rail of the switch. Also when a train is approaching a station the brakes are normally used and heat is being generated in the bogie and underframe, causing ice and snow to melt. In addition, in bigger cities the temperature is usually higher than in the countryside. This helps the ice and snow to get loose and fall off.

As the contact zone between a piece of ice and the main (heated) rail is very small, it takes a long time to melt the ice. These blockings can in the short term only be removed manually. In big stations with

⁴⁶ Photo from Banverket in report 'High-Speed Train Operation in Winter Climate' (2006)

staff available, this can be arranged. Out on the lines it can almost only be done with help of the driver who has to stop in front of the switch, get out, remove the obstacles and then continue the journey. For all fast running trains this is most time consuming.

In the last years there have been a few technical solutions presented to the switch winter problems. One of them takes care of the problem with fallen pieces of ice between the tongues and the rails. The patented solution shown in Figures 56 and 57 is from Idéus in Sweden.



Figure 56. The proposed technical solution with a covering flexible lip that is hidden under the rail head when the switch tongue is closed.⁴⁷

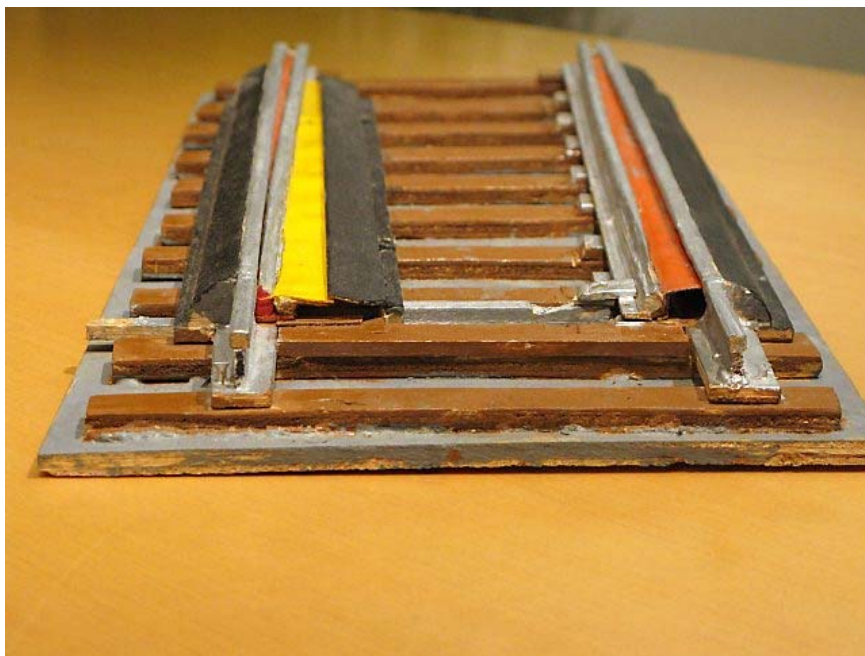


Figure 57. A model of the patented switch that will not be affected by fallen ice pieces.⁴⁸

In this way the open areas are covered and snow and ice will not get the same possibility to block the altering of the switch. A second advantage is that when brushes are used to clear switches, the brush does not have to reach down some 200 mm between the rail and the tongue to clear the normally open area between them.

This switch is not yet tested in service, and operational and economic advantages are to be evaluated.

⁴⁷ (2010) Photo from Idéus konsultteknik HB

⁴⁸ Ibid.

Suggestions for better switch functioning:

- Use technical solutions for example as shown in Figures 56 and 57 to hinder snow and ice to fall between the main rail and the tongue in important switches.
- Use technical solutions as shown in Figures 58 or 59 to remove blocking ice and snow in important switches by either melting it or blowing it away. However melting snow to water gives a problem with freezing water in other locations and is probably not a good solution in areas with constant low temperatures.

■ Melted ice lumps at tongue rail by hot water and injection pressure

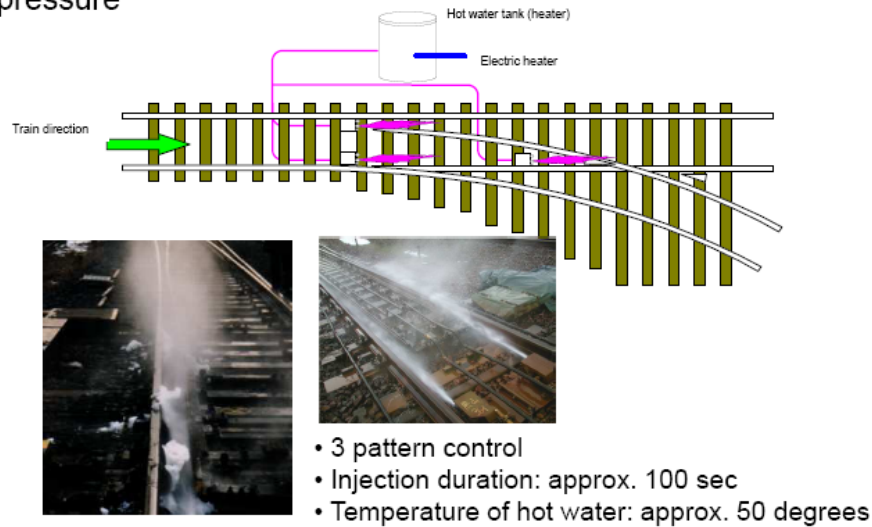


Figure 58. Hot water jet injection melting device at East Japan Railway Company.⁴⁹

■ Removed ice lumps at tongue rail pneumatically

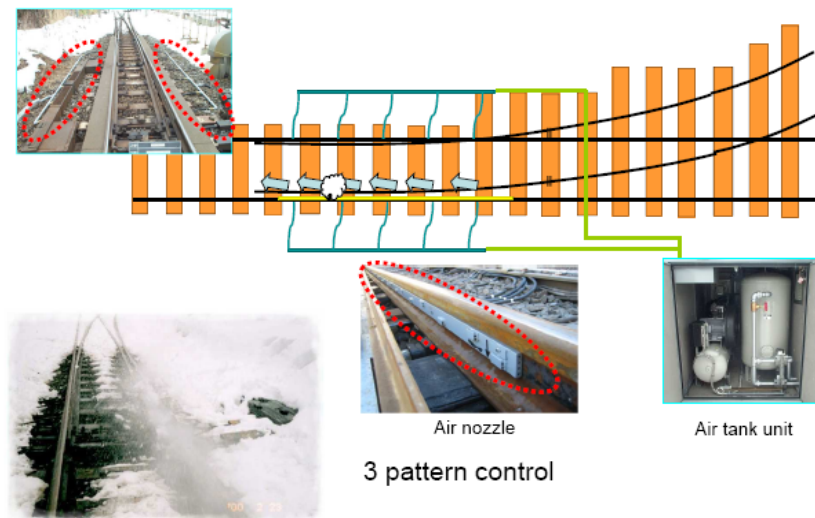


Figure 59. Air injection snow removal device at East Japan Railway Company.⁵⁰

- Resources for manual or mechanical clearing of switches from snow and ice are needed if not efficient technical solutions can be provided.

⁴⁹ (2011) Countermeasures for snow disasters of JR East by Akihiro Nakahata

⁵⁰ Ibid.

3.4.4 MAINTENANCE

To reduce the winter problems the following has been proposed:

- The electrical heating must be checked before each winter period.
- The lubrication of switches must increase in the winter time. The heating has the effect that more lubricant is necessary.
- The small length movements in the track must be observed and the correct distances to the rods must be kept.

A passing train generates small movements of the track. These movements in the ballast can give as a result that the rods for a switch comes too close to a sleeper. Then there is a risk that they freeze to the nearest sleeper and the switch motor cannot move the switch fully or not at all.

- The supervision of important switches must generally improve.

Data supervision has been tried on a number of switches by measuring the current to the switch motor, see Figure 60, showing the principal configuration from a Swedish brochure. In a switch that moves rather sluggish, the current increases and the maintenance people can get the information direct to their mobile telephones. A slow motion is often the pre-stadium to not working at all. The results so far are very promising.

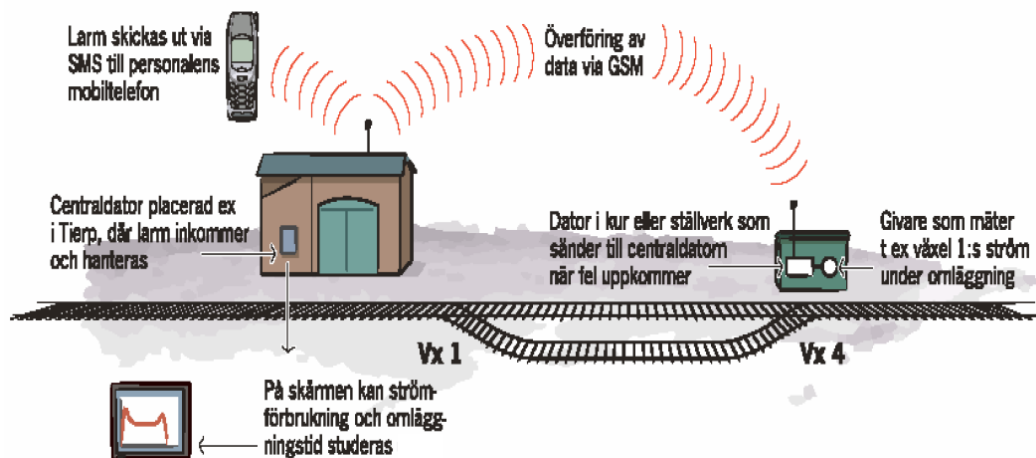


Figure 60. The current and the time for manoeuvring a switch are measured. If the result not equals the expected value, a warning signal is sent out directly to the maintenance people's mobile telephones.⁵¹

3.5 PLATFORMS AND PLATFORM TRACKS

Platforms and platform tracks generate special risks regarding passenger safety.

3.5.1 PLATFORMS

At platforms passengers risk slipping and falling if the ice and snow is not removed. Furthermore a platform often has a small inclination from the middle towards the track to make the rain water run off to the track. Some platforms have a trench in the middle instead and the inclination is from the track.

⁵¹ (2006). *Förebyggande övervakning – FÖSA*. Information brochure, The Swedish National Rail Administration (Banverket Produktion).

Besides often being hard to clear from snow – there is often no good place to put the snow – another problem related to platforms is that trains drop ice and snow on the track when stopping. Ice and snow fall off the trains due to the increased temperature in the bogies and underframe after a train has been braked to stop. Later a high speed passing train can hit it and throw it onto the platform.

At curved platforms there is a slightly bigger or smaller gap between the train and the platform which also can result in injuries especially on slippery platforms, if the gap is not bridged by a movable footstep or equal. This is why:

- Platforms shall be cleared from snow – and sanded – shortly after a snowfall. In case of very intense and heavy snowfall the platform need to be cleared also during the snowfall.
- Platforms could be heated.
Such a system would reduce the need for snow clearing, but the solution is believed to be expensive. The important thing is that the platform is cleared and not slippery.
- If the platform inclination is towards the middle instead of towards the track it reduces the risk that people fall on the track when the platform is slippery. This however complicates the drainage of the platform.
- As there is a risk for passengers that passing trains run into lumps of ice in the track which then are thrown up on the platform by the plough, the platform tracks shall be cleared from snow and ice regularly.

3.5.2 PLATFORM TRACKS

If there is too much ice and snow in the track a passing train will throw it away with its plough and eventually cause injuries to people on a platform, see Figure 61.



Figure 61. A platform track with a lot of ice that has fallen of stopping trains at a main station.

The problem has been proposed to be dealt with through the following actions:

- Prevent trains from accumulating snow as far as possible (see Chapter 2.2 ‘Snow packing’ for further information).
- Decrease the speed at platforms.
- Separate high-speed tracks and platform tracks.

- Improve the track clearing at platforms and keep platform tracks were passing trains are expected clear from ice lumps. Especially around switches ice pieces tend to fall off passing trains even at low train speeds, see Figure 62.



Figure 62. Ice lumps fallen off in a yard from low speed passing trains close to switches.

3.6 OVERHEAD WIRE

The overhead wire or catenary is a sensitive system in itself and winter makes the situation even worse. It is more common that the overhead wire is torn down wintertime compared to other seasons.

A torn-down overhead wire can be the outcome of several situations or combinations of these. Nearby trees that carry heavy loads of snow can for instance fall over the wire and subsequently tear it down. Most other causes have to do with passing trains and the contact with the pantograph of which a few influencing factors follow:

- Through excessive wear, which could be the result from arcing, ice or rime on the overhead wire, the carbon strip of the pantograph can be damaged, which next can tear the catenary down.
- The catenary is extra vulnerable at points where the wire is changed into another one. During wintertime these locations become even more sensitive and if a train with a damaged pantograph passes there is risk for tearing down the catenary.
- In cold climate the overhead wire cannot move as easily as usually. This has to some extent been solved with heavier weights that modify the tension conditions. However it is possible that the overhead wire is not in its right place and a passing train can then rip the overhead wire down.
- In coldness practically all movements get harder and more difficult. For example the pantograph may not have the same suspension characteristics all year around. Deviations and imperfections therefore have larger importance during winters. The same goes for the overhead wire and its tension weights.

Another problem occurs when ice builds up on the overhead wire. Ice makes the wire heavier and hinder current conduction to the pantograph. This can cause speed restrictions and power failures, compare Chapter 2.9.3 'Raising and lowering of the pantograph'.

Besides keeping the pantographs in good conditions the following measures have been proposed in order to increase the catenary's winter durability:

- Heat the catenary.

It could be necessary to heat the overhead wire at some locations during extra tough weather conditions. Sometimes it is sufficient with the heat generated by the traction current why a

frequent traffic is preferable from this aspect. Sometimes an additional reactive current is used to prevent or reduce the build up of rime on the contact wire.

- Measure and forecast ice accretion on the catenary.

By the use of geographical information systems the ice build up can be both measured and forecasted in time for preventive maintenance. Data from the system can also be of help for planning of maintenance operations.

- Put anti-freezer on the overhead wire.

There are a few methods to put anti-freezer on the over-head wire. One of the systems is used on the Bremen tramway and also on the Roslagsbanan railway system north of Stockholm, Figure 63. The anti-freezer reduces the rim and ice on the over head wire and hence the arcing, which makes the carbon of the pantograph last longer.



Figure 63. Dummy pantograph for putting glycerol on the contact wire to reduce the arcing⁵².

- Have the area next to the track well cleared from trees.

Trees close to the track should be removed in order to prevent them from entering the free space when they are burdened with snow and ice. It is also preferable that stations are not designed with roofs that lead snow and ice towards the catenary.

3.7 BALLAST PICK-UP

Trains running at high speeds can make macadam stones lift from the ground. These stones can cause damage to whatever gets in their way. When a stone hits a running train, it receives more energy. An avalanche effect is created if the stone hits the ballast and causes other stones to lift. The damage caused to the train can be most expensive to repair. Ballast stones can of course also be thrown sideways and collide with for example other trains, buildings or still worse, human beings.

The phenomenon of ballast pick-up is not fully understood yet. Amongst others is it caused by snow and ice that fall off the train and hit the ballast which starts the process. Besides this the lifting of ballast is believed to be influenced by;

- the underpressure just behind the front or the rear of the train,
- a sail-effect caused by ice and snow located on top of the ballast,
- vibrations due to train passage that reduce the friction among the rocks and make them lift easier and

⁵² (2011) Stemmann-Technik GmbH *Railway Technology Systems*

- whether the macadam is frozen or not – a frozen track may reduce some ballast pick-ups.

In Japan, ballast pick-up is reported to be a problem for a very long time. The literature study carried out suggests that ballast impacts as a consequence of trains dropping ice and snow is one of the largest winter problems in Japan. The following quote shows this and a Japanese approach to solve the problem.

“One unexpected problem started with a heavy snowfall at Sekigahara (between Nagoya and Kyoto) in December 1965. Shinkansen trains running through snowfall at very high speeds blow up the snow on the track. The blown snow sticks to the underfloor equipment and freezes rapidly into ice. When the train enters a warmer region, the frozen ice thaws and drops at high speed from the train causing the ballast to fly up and seriously damage the underfloor equipment. There was no immediate solution other than reducing speeds to 70 km/h in snow. Later, water sprinklers were installed along the track in order to melt the snow, but speeds in snow are still restricted even today (although not as low as 70 km/h in most cases), because excess water sprinkling can damage soil embankments. Drawing lessons from this, the Joetsu Shinkansen, which runs through a very snowy region north of Tokyo, was built entirely on concrete viaducts and large amounts of warm water are sprinkled during snowfall.”

(Saito 2002)

There have even been Japanese reproductive tests of thrown ballast in order to clarify the actual conditions of the phenomena. The behaviour of ballast being struck by ice and snow blocks at high speeds was revealed. Figure 64 holds pictures of this test.

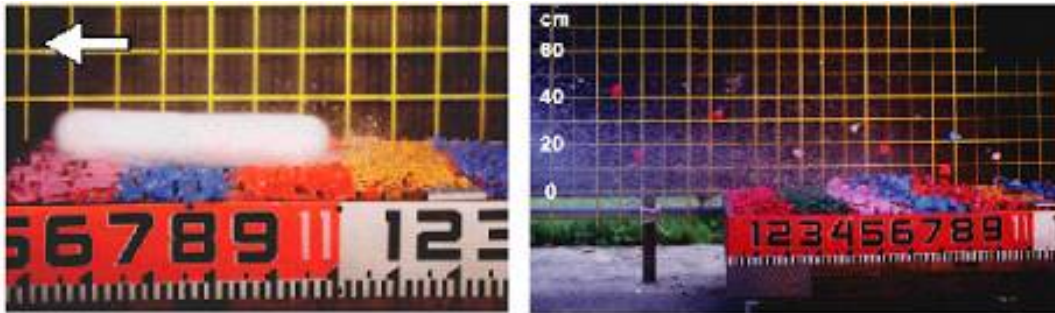


Figure 64. Japanese reproductive test of ballast flying phenomenon⁵³.

The test clarified the relationship between the number of thrown ballast stones and the mass and speed of the snow and ice hitting the track. This is described in Figure 65. In this figure the numbers of stones thrown higher than 33 cm are of importance as this is the distance from the ballast to the train's underframe.

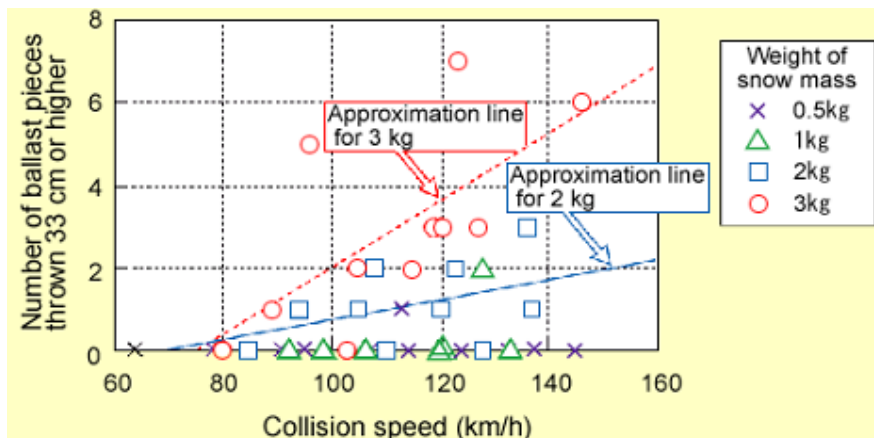


Figure 65. Relationship between collision speed of snow/ice mass and number of stones thrown 33 cm or higher⁵⁴.

⁵³ Railway Technical Research Institute, Tokyo Japan (2004). *Clarification of Phenomenon of Ballast Thrown up by Snow/Ice Falling from the Train*. (Electronic) Available: http://www.rtri.or.jp/rd/openpublic/seika/2001/01/safety_E02.html.

⁵⁴ Ibid.

Ballast pick-up is assumed to increase with the train speed. At speeds above approximately 160-180 km/h an increasing tendency for ballast pick-up has been noticed. The higher the train speed the higher:

- energy of the snow and ice blocks that fall off the train,
- energy of stones ricocheting between train and track and
- underpressure and air turbulence under the train.

Ballast pick-up and its effects can be limited through the following measures:

- Lower the macadam ballast level.

In Finland, Norway and Sweden the macadam level has been lowered approximately 3-5 cm below top of the sleeper. The lowering is not done from aerodynamic reasons but primarily for letting the falling ice and snow crush against the sleepers' concrete edges. Lowering the macadam level has in fact proven to be very effective for speeds up to 200 km/h and has led to the situation that some people do not consider ballast pick-up a problem any longer.

Tests performed within the "Gröna Tåget" programme has shown that 1,5 to 2 kg heavy ice blocks falling from the height 1,5 m always will be pulverized when hitting sleepers if the ballast level is lowered some 3 – 5 cm below top of the sleepers. These tests were performed at speeds of 200 to 250 km/h.

In Germany the ballast level between the sleepers has also been lowered, however speeds are reduced to 200 km/h at some extreme weather conditions.

- Reduce the train speed.

As already mentioned this is the procedure in Germany but also in France. However in these countries this is an action only necessary during a few days per year. In the Nordic countries this is not considered an acceptable solution except on very rare occasions.

- Decrease the distance between sleepers.

This is mainly a theoretical measure that follows the same principle as a lowering of the macadam level.

- Make the underside of the train as flat as possible.

The underpressure below the train can be reduced if the train's underframe is designed as flat as possible. However, bogies and ploughs will always create turbulence under the train.

- Apply train designs that accumulate as little ice and snow as possible.

- Strengthen areas subjected to ballast pick-ups, see Chapter 2.3.1 'Wheels, axles and axle boxes'.

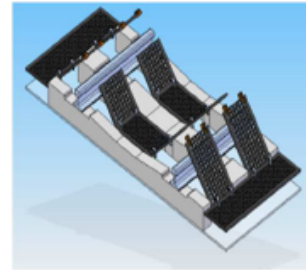
- Cover the ballast with a net.

If the ballast were kept in place with some kind of net, the ballast stones could not lift. This measure is frequently used in eastern Japan. This method has a negative impact on the time for doing track maintenance such as tamping.

- Cover the ballast in other ways that interferes less with the maintenance, see Figure 66 showing a Japanese line with a cover to stop the ballast pick-up.

■ Purpose of installation

Prevent damages to places along railway-tracks and glass breakage in vehicles from ballast flying when impacted by falling ice lumps



Developed quick-release ballast screen for effective maintenance

EAST JAPAN RAILWAY COMPANY

Figure 66. Ballast screen at East Japan Railway Company with a quick-release ballast screen for effective maintenance⁵⁵.

- Use ballast-free tracks (slab-track) for high-speed trains.
Slab-track is considered to be the most effective solution. However, slab-track is considered to have disadvantages compared to ballast track. It is for example much more expensive and makes maintenance more difficult. There is also a risk that noise will increase.
- Apply heat to surfaces on the train that accumulate snow. See Chapter 2.2 'Snow packing'.
- De-ice trains from packed snow and ice. In particular this solution is of great benefit also for the train's function and reliability in winter climate.

3.8 TRACK CAPACITY

The track capacity becomes even more critical wintertime when the track and rolling stock are burdened with winter problems. As already mentioned it is for example hard to clear tracks from snow when there are no alternative tracks and no vacant capacity. In traffic systems where different train services share capacity, high-speed trains can also be disturbed.

With high utilisation of the tracks the traffic system gets vulnerable to disturbances, which will be the case in the winter months. Consequently more tracks are needed especially on locations where traffic volumes are close to the capacity limits. It has been proposed to:

- Reduce the number of trains during at least a part of the winter period. Notice that this not necessarily means that trains need to be cancelled.
- Re-routing some trains.
To be able to keep up with the demands for transportation the reduction can in special cases be solved by re-routing some trains to other (longer, slower etc.) lines or re-scheduling them to off-peak hours. This solution may be both relevant and acceptable for not time-critical trains. With reliable weather forecasts and proper planning this can be decided at least 12 hours in advance.

⁵⁵ (2011) Countermeasures for snow disasters of JR East by Akihiro Nakahata

3.9 OPERATION

No matter if a high-speed train service – with aspects on both rolling stock and infrastructure – runs smooth during winter, trains on other line sections and other trains on the same section may cause disruptions. This comes to that:

- Since train services are extra vulnerable wintertime more track capacity is needed at certain locations.
- In mixed traffic, attention has to be paid to the winter maintenance of the conventional trains as well.
- The passenger information system, both on board the trains and at stations and platforms must give frequent and correct information at disturbances.

The opposite is shown in Figures 67 and 68 from the 25th of January 2010. The platform and the platform information system are shown in Strängnäs some 80 km south-west of Stockholm, on the fairly newly built Swedish high-speed single line railway. The shown information was that the trains leaving 13.40 and 14.20 in the afternoon from track 1 were cancelled, but that the train to Stockholm 15.20 and the train to Eskilstuna 15.40 were to leave from track number 1, the only platform track at the station.



Figure 67. Track and platform in Strängnäs covered with snow Monday afternoon 25th of January 2010.

Avgående tåg - Train departures				
Tid	Avgående till	Ber.tid	Spår	Anmärkn
13.40	Eskilstuna			Regional Inställt
14.20	Södertälje Stockholm			Regional Inställt
15.20	Södertälje Stockholm		1	Regional
15.40	Eskilstuna		1	Regional
Ankommande tåg - Train arrivals				
Tid	Ankommande från	Ber.tid	Spår	Anmärkn
13.39	Stockholm Södertälje			Regional Inställt
14.19	Eskilstuna			Regional Inställt
15.19	Eskilstuna		1	Regional
15.39	Södertälje Stockholm		1	Regional

Information
 Pga rådande väderlek drabbas tågen av förseningar, vissa tåg är dessutom inställda. Var uppmärksam på skyltning och högtalarinformation.

Figure 68. Actual platform information in Strängnäs Monday afternoon 25th of January 2010.

High-speed train operation in winter climate

The extra information says: "Due to the actual weather situation there will be train delays and some trains are cancelled. Please pay attention to information given over the loudspeakers and information screens."

The true story was that all service had been closed on the line over the weekend and the line was not opened with regular service until two days later. There was no passenger information about this at all.

On the other hand it is better to close the line if there is not enough capacity to keep it open than to run the trains until one gets stuck. However, in modern high-tech countries with frequent winter climate it is important to keep roads, railways, airports and sea routes open for the more and more common just-in-time processes that the whole society nowadays is a part of.

During the period November 2010 – March 2011 the Swedish passengers were 4,1 million hours delayed, giving a cost of 2,4 billion SEK (around 260 million Euro) for the public sector according to a study performed by the Swedish Transport Administration which was published in leading Swedish newspapers⁵⁶.

The same study indicated that the delayed freight trains gave a cost of 200 million SEK (around 22 million Euro) for the public sector during the same period. These 200 million SEK comprise the direct costs within the transportation system. They do not include the costs for all the afflicted companies. That cost can probably be counted in billions instead of millions.

To be able to optimize the output, i.e. to have as many trains running as possible according to the agreed prioritization, there must be a very tight cooperation between the Traffic Control Centres and all the different operators that in one way or the other are involved in the railway operation. That is why:

- The organisation must have one person dedicated to take the decisions which trains to run, which to delay, which to re-route and which to cancel.

Plans have to be made up in advance, but when it comes to reality the responsible person must be able to take other steps if they for instance can help up a chaotic situation.

- There must be cooperation on many organisational levels between the different parties with the aim to solve the problems for the overall rail service and not only for the short-sighted needs.
- Sufficient time must be given to snow clearing activities. Also it is vital to use every spare time to clear areas from snow and prepare for the next snowfall.

⁵⁶ DN 20 June 2011 *Winter train delays cost Sweden 'billions'*.

4 CONCLUSIONS AND SUGGESTIONS

Winter has not proven to be a question of high priority all year around. This can for example be understood from the fact that;

- winter causes problems every year and sometimes even seem to come as a surprise,
- mild winters tend to get actors within the railway sector to more or less forget about large parts of the winter problems,
- winter solutions are often acute, regional and of short-term.

In order to facilitate the winter problems an exhaustive responsibility together with a more long-term perspective on the winter questions is required.

Above this, the performed investigation has among others resulted in the following conclusions and suggestions:

- At some winter conditions the demanded brake forces cannot be guaranteed. Winter conditions can either entirely or partially put brakes out of function. This could get the most severe consequence which increase with the speed. The problem also leads to uncertainties regarding how the emergency brake should be handled.
- There are a few general rolling stock winter problems - however the majority of the problems are vehicle-specific with or without carbody tilt. Many winter problems are thereto more or less independent of the train speed.
- As regards the rolling stock design it is in some situations a question of priority; either good maintenance possibilities or good winter durability. For example the bellows that the Swedish X2000 were fitted with or the brake disc covers and other kinds of winter protections can sometimes complicate maintenance and visual inspections.
- Ballast pick-up by falling ice blocks is a big winter problem in some regions that has not been fully solved. The situation can be much improved by lowering the ballast level to 3 – 5 cm below top of the sleeper.
- There is not sufficient de-icing capacity in most regions in order to secure necessary rolling stock maintenance in time without risk of disturbing the train operation.
- Contacts taken indicate that speed restrictions wintertime are rather common in other European countries – both France and Germany lower the speeds if the winter climate demands it. This leads to the conclusion that there are high-speed dependent winter problems that cannot be managed in these countries today.
- European standard designs are not always practically applicable during Scandinavian winter conditions. The coming EN standard “Environmental conditions” can hopefully drive standards a step further.
- Winter puts high requirements on the rolling stock why the competence of the purchasing organisations, as well as in the supply industry, is of great importance. Many winter problems can be prevented during the design phase.
- Track clearance now-a-days needs to be improved in many regions. Short sighted money-savings can stop or severely disturb train operation for a month or more. It has to be accepted that preparedness for winter conditions is not free of charge.

Railway operations should be compared with airports where they have modern up-to-date trucks for the snow removal. They cannot afford to close down for a long time.

- Remote-controlled switches must function in winter conditions. It is not acceptable that they (as usual) not function because of snow and ice when needed.
- An overall winter organization seems to be needed as there are so many different actors working in the railway sector.

High-speed train operation in winter climate

- Winter issues must be on the agenda all year round. It is planning, performing, evaluating and improving which should be a process going on 365 days a year, at least in regions where winter climate not is expected to come as a surprise.



Figure 69. To keep main lines open big snow throwers or ploughing locomotives are necessary. The photo shows a 1235 kW diesel locomotive (ex class Tb) clearing the second track. The main track has already been cleared on this location close to Gävle some 200 km north of Stockholm.⁵⁷



Figure 70. In Swedish yards a two-axle service vehicle often is used for snow clearing, usually with a rotating brush at the front. It is an effective way to clear switches in the beginning of the winter season. However when there is a lot of snow and high snowdrifts, the effectiveness goes down.

⁵⁷SR Östergötland, February 24 2010. *Jämvägens snöplogslök skrotas.*

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Leif Andersson, *Project Manager Rail Traffic Fortum*, & Kent Fröjdman, *Supervisor Signalling Systems Fortum*

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Figure 71 and front figure. Snowsmoke around passing X2 trainset in Södertälje south of Stockholm in January 2010. Notice the intense snow smoke at the bogie level.