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Winter Technologies for High Speed Rail

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Abstract:

High speed rail are operatives in many countries in the world. The technology has evolved for about 40 years now and is mastered by several worldwide companies. However, high speed rail are fairly new in Nordic countries such as Sweden and Finland and few development has been done so far to deal with high speed rail in hard winter conditions. Japanese Shinkansen experiences snowfall and cold weather but nothing compared to the Norwegian long, cold and snowy winters over the whole country.

With the possibility of building a high speed rail in Norway in the future, NSB and CargoNet realise that few technologies are published in regard of winter operations. However, after winter 2009/2010 overwhelming snowstorm throughout Europe, most countries started analysing the situation to avoid any major winter shortage in the future. Many problems occurred on the networks either on the rolling stock, infrastructure or operations.

The goal of the thesis is to analyse the proposed winter technologies from an economical/beneficial point of view to propose the best one to the industry. Literature study provides information about the available technologies and interviews with railway industry actors confirms its efficiency in case of an existing technology and the potential success in the event of a new one.

The analysis of data provided that propylene glycol de-icing was the most cost effective technology for the rolling stock and should be implemented throughout any winter railway network. It has been proven effective by the industry. Likewise, snow brushes and fences combined with improved switch heaters – with the use of cameras and sensors – will reduce manual cleaning and increase the efficiency of the entire infrastructure network. For the planning, many alternatives are available to improve the operations but two main recommendations are to be kept in mind; Communication between weather forecasting groups, infrastructure managers, trains operators, customers and authorities is primordial as well as being ready to react to any situation by having emergency plans before the undesired situation arise.

Keywords:

1. High speed rail
2. Rolling stock
3. Operations
4. Winter
I. PREFACE

This Master thesis is done as a part of the Master in Project Management held at NTNU from fall 2009 until spring 2011. It was written in the last semester of the program.

The study was initiated after the mandate of Jernbaneverket to study the feasibility of a high speed rail in southern Norway. With possible major modifications of the railway industry in Norway, NSB and CargoNet went through previous studies to notice that winter-related problems were too little addressed mostly concerning winter organisation.

The report explains the latest technologies helping reducing the effects of winter conditions for Nordic high speed trains. The objectives are to analyse the technologies’ cost with their benefits and suggest the use of the most beneficial one. Norwegian context is mostly looked upon but results can be applied to any other Nordic countries such as Sweden, Finland, Russia and Canada.

I would like to thank the project supervisor, Nils Olsson, for his assistance and recommendations during the redaction of the project. I would also like to thanks CargoNet and NSB for their collaboration.
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1 INTRODUCTION

1.1 Background
High speed trains have been introduced in Scandinavia in 1990 with the Swedish X2000. Despite harsh winter conditions often delaying trains, few have been done so far to reduce the consequence of ice and snow on train speed. Reasons are that the train manufacturers sell more trains in warmer countries than Sweden and Norway. (Lennart Kloow, 2006) Moreover, even though some of those countries might experience snowstorms, in no way they are comparable in size and frequency to Scandinavian ones. Trains can thus be delayed or cancelled once in a while without highly affecting the operator’s reputation. This situation would be catastrophic in Nordic country as it would happen throughout the whole winter. The literature study shows the development made so far to deal with winter condition such as rolling stock and infrastructure winterisation. The technologies ranging from de-icing to new design are described. Further, the development of new winter scheduling is studied considering that in Scandinavian countries even the best technology cannot melt away a metre of snow in a day. In that case, a specific procedure is to be applied.

1.2 Initiation of this study
The study was initiated after the mandate of Jernbaneverket to study the feasibility of a high speed rail in southern Norway. With possible major modifications of the railway industry in Norway, NSB and CargoNet went through previous studies to notice that winter-related problems were too little addressed mostly concerning winter organisation.

1.3 Study purpose
The study firstly describes the winter conditions prevailing in Scandinavia, with emphasis on Norway. A comparison with other countries experiencing winter condition such as Japan is brought to understand the difference between snowfall and winter length.
The different technologies to reduce ice and snow build-ups on both rolling stock and infrastructure are described. The technologies will then be divided in two categories; active or passive.

The main part of the study consists of implementing winter operations for winter time. It ranges from the number of extra employees to assign, the change in timetable and the procedure to apply when a snowstorm is underway.

All the proposed solutions are presented to resource people from the railway industry followed by an interview to better understand their needs and to get their thought on those solutions.

The objectives to meet with this report are to provide information for the railway industry about winter technology for high speed rail and on the ways to implement them. It provides a classification of winter technologies and the analysis of their cost compared to the benefits. After reading the report, the infrastructure managers and train operators will have a better understanding of the available and technologies to help coping with winter problems and which one are best.

The thesis focuses on the following central points:

- Worst winter scenario for the railway industry
- Problems arising during winter operations
- Classification of the technologies in three categories (rolling stock, infrastructure, operations)
- Classification of the rolling stock and infrastructure technologies between active and passive protection
- Analysis of the technologies’ cost and their benefits
- Recommendations on the most promising technologies for the railway industry
1.4 Limitations

The limitations of the research are concerning the implementation of the technologies. Most of the technologies are promising but not necessarily profitable either on a short or long term.

On the one hand, the use of heaters on the train thaws ice perfectly but the energy consumption makes it a less interesting method. The same applies to the use of hot water to melt down ice and snow on the railway. It is surely an efficient way of thawing snow but it can only be used on a short segment of track as a lot of energy is required to warm water.

On the other hand, the snow procedure might work on a theoretical way but be completely inadequate on field. This said, only experience can ensure that a procedure is flawless. Updating the procedure by adapting it to real life is a good way to have a better winter condition tool.

1.5 Report structure

The report is divided in eight sections, each of them divided in subsections. A literature review is done for the most important sources used in this report. The methodology used to find the sources and the HSR terminology follows that section. The main part of the report consists of the description of the rolling stock and infrastructure technologies as well as detailed winter management programs. Analyses between the different technologies help catching a glimpse at the best available options. Finally, a conclusion will be drawn for the whole report followed by the list of references used in the report.
2 METHODOLOGY

The methodology used for the report is to find all the technologies used in the transport industry to reduce the effect of ice, snow and frost during winter. The technologies will be divided between infrastructure and high speed rolling stock. Even though improvements will reduce the risk of delays for high speed train, snowstorms might be overwhelming the melting systems impeding train speed. However with adequate communication between rail infrastructure owner, train operators and meteorologist, it is possible to be prepared to ease the hassle. By looking the different snow operations procedure for other means of transportation, the rail industry will be able to quickly deal with any kind of snowfall.

2.1 Literature review

The information taken for the redaction of this report were mainly found on Internet as winter management is fairly new thus poorly represented in books. Search engines were used to find subject related to rail operations in winter. By searching on Google the keywords “High speed train winter”, over five million hits were found.

However, the first hit was one of the most important and complete report made concerning high speed rail operations in winter in “HIGH-SPEED TRAIN OPERATION IN WINTER CLIMATE”. The study was made by Transrail, specialised in services to train operators, rolling stock manufacturers, infrastructure entrepreneurs and maintenance suppliers. They also offer services to authorities, administration and other stakeholders. Founded in 1994, Transrail now has 11 employees with a turnover of about SEK 15 million. The study was performed within the Banverket’s research project, Gröna tåget. This project aims to develop competence around passenger rail service operation in Sweden. It will help the stakeholders to better deal with special Nordic conditions found in Sweden but also in other Scandinavian countries like Norway and Finland. Partners are Bombardier, technical universities and railway industrial companies. This study is the most complete one made so far concerning high speed rail in winter conditions. The investigation compiles knowledge and experience with winter HSR, mostly focused on
Scandinavian countries. Nordic railway industry stakeholders were contacted to get more information on coldness problems and solutions taken so far to deal with it. The main conclusion is that winter is not a high priority for many stakeholders as it is not an all year round worldwide issue. Consequently, few solutions have been tested as the financial benefits rarely justify the investment. As it is a preliminary study, further investigation is expected to take place to set guidelines and standards for winter high speed rail running at speed of 200 km/h and more. Once this backbone was found, its bibliography brought more information about possible new sources.

Another important document was found when the study was underway on the International Union of Railways (UIC) website. Even though the report is in average English, “WINTER AND RAILWAYS – STUDY” includes precious information on winter operations as well as on rolling stock and infrastructure technologies. The study also linked me to all the UIC reports concerning winter technologies. Many of the technologies found there were unpublished.

With the help of my supervisor subscribed to a railway journal, the “INTERNATIONAL RAILWAY JOURNAL” was used at first for an article on winterisation. By browsing the journal website and looking for keywords such as winter, snow and ice, three other articles were found concerning propylene glycol de-icing, use of chemicals and winterisation.

The first article is a review of the corrective measures taken by Eurostar after winter 2009 Channel Tunnel’s trains breakdown. Passengers’ evacuation took hours to complete, delaying them for over 14 hours. An inadequate winterisation program combined with overwhelming snowstorm and human errors caused four trains to be delayed. In 2010, a new revamped winterisation programme was set to avoid a major breakdown in the tunnel. Much more inspections and improved communication allows Eurostar to deal with winter conditions as soon as it appears. For example, alternative cross-channel routes are rapidly set with P&O Ferry in the even that trains are cancelled. Also, cameras were installed in case real-time information is needed.
In another article, Dr Foster Ross reveals Kilfrost technologies that can overcome problem with frost, snow and ice. It mostly deals with snowy and icy platforms but also with third rail anti-icer. The chemical products are specially developed for the rail industry where products have to be effective in sub-zero temperature without high electrical conductivity to avoid short circuit.

The third article brings out de-icing solutions based on the airplane glycol system. Thomas Jemt claims that use of chemicals is way more efficient than hot air as a medium for transferring heat, thus melting ice and snow more efficiently.

Finally, many sources were found by knowing the name of a technology and finding it on search engine. For example, searching “propylene glycol de-icing railway” yielded about 15000 results, most of them directly linked to the related technology. Also, by searching “problem train winter 2009-2010”, one of the worst winter experienced by the railway industry, many new sites confirmed the different problems encountered that winter. Another journal “JAPAN RAILWAY & TRANSPORT REVIEW” was used in previous research and confirmed as an accurate source of information.

2.2 Interviews

Interviews were done with actors of the rail industry, NSB and CargoNet, to comprehend their biggest problems encountered and the way they dealt with it.

The meeting was held on Wednesday, May 18th at CargoNet office and NSB office and maintenance office in Oslo. The contact people from CargoNet were train operation manager, technical engineer and technical chief for locomotive. Two meetings were done with NSB, with the analysis department and with the technology department.

A presentation of all the findings made in that thesis was done before the interview to present the new technologies and older one that could be used in the railway industry.

A list of questions was sent to the companies few days before the interview. First questions were concerning the previous experience with winter and to know when the beginning of their winter season was. Their worst case winter scenario was also...
explained by clearly stating which kind of snow and temperature are the worst for the rolling stock and infrastructure.

The second part was concerning rolling stocks’ problem and how they dealt with it in the past. The technologies found were explained in a presentation and questions concerning the possible implementation of those technologies for the company were questioned. Some of the technologies were seen as inapplicable for Norway or really promising for the future.

The third part was about the infrastructure problems. Even though CargoNet and NSB are not responsible for the maintenance of the infrastructure, they are both affected by the work done by Jernbaneverket. Different technologies were presented and discussion about their efficiency was held.

Finally, the questions about the operation part were concerning the winter procedures. In the first place, the interviewee described their winter procedures. Then new procedures were proposed to deal with winter in the future years. Few procedures were considered interesting but many were seen as theoretically good but practically difficult to implement.

The list of questions is included in the APPENDIX 1.

2.3 Terminology

The lexicon found in APPENDIX 2 was originally produced by the Railway Systems Group at the University of Sheffield in cooperation with Railtrack (now Network Rail) and other organisations. Staff at the University of Sheffield and the team of The Railway Consultancy updates the Lexicon on a regular basis. In general, the UK term "railway" is used rather than the US term "railroad". (Schmid)
3 WINTER PROBLEM

In most countries, high speed train never runs in sub-zero temperature. In case of heavy snowfall or freezing temperature, the trains are slowed down to avoid derailment (Jerbaneverket, February 2011) However, this counter measure applies only a few times per year while in Nordic countries the situation is standard. To better understand the Nordic climate, an overview of the Norwegian climate will be given.

Temperature in Norway varies a lot from North to South. The lowest temperature recorded in Norway was -51.4°C in Karasjok in 1886 while the highest one was 35.6°C in Nesbyen in 1970. This said Norwegian winters always get down to chilly sub-zero temperature.

During winter, precipitations are likely to be in form of snow, mostly inland where snow will be frequent but moderate as the temperature are lower than on the coastline. Snow covered periods vary but snow will cover the ground most of the winter. On the coastline, precipitations will be a mixture of snow and rain, commonly getting more than half a metre of snow in a day. Snow will remain for a few days before melting down when temperatures reach over freezing point. (Jerbaneverket, February 2011)

Previous studies were made related to the use of winter technologies for HSR. Winter technologies date as far as 1966 with the use of sprinkler on the Shinkansen lines. (Toshishige Fujii, 2002) (Hood, 2006) Other technologies are more recent such as propylene glycol de-icing. The previous literature dealing with those technologies are reviewed here.

During winter 2009/2010, many problems occurred following the snowy and cold winter. Eleven countries experienced rolling stock problems ranging from couplers problem to trains picking up ballast which damaged under frame equipment. Amongst those countries, Norwegian NSB experienced problem with the central coupling, the HVAC and toilets freezing. (Enno Wiebe, Factsheet root causes, 2010)
Most of Europe experienced infrastructure problems with 18 countries from Spain to Finland. Norwegian Jernbaneverket experienced problems with rails and welding, switches and crossings, catenary and performance of modern equipment for snow clearance.

A problem highly encountered by CargoNet is the wheel wearing during winter. For example, more than 2000 wheels had to be reprofiled in winter 2010/2011 which represents more than a fourth of the wheels. The reason why the wheels are wearing faster is the low-temperature which increases the tensile stress on the steel. The problem highly affects Nordic countries, from Norway to Canada. “Cold weather is hard on equipment in general. But winter operation is especially hard on wheels. BC Rail, for example, spent $4 million - $4.5 million per year on wheels, against a $13-million budget to maintain 10,000 cars. Most of these wheels were prematurely taken out of service.
because of shelling, out-of-round or other high-impact conditions that hammered the rail during the coldest (highest tensile stress) time of the year.” (Hooper, 2008)

Sweden also experienced severe problems in 2009/2010 with an increase of 150% of cancelled trains. The information centre daily calls rocketed up from 12,000 to 100,000. One of the major problems was the 30 tonnes ice build-ups on the overhead wire from Göteborg to Stockholm. (Enno Wiebe, Factsheet winter management, 2010) The delays were the double of a normal winter increasing the public treasure cost of SEK 3 billion. The problem was found to be in four different areas; Infrastructure, contractors’ capacity, internal management and process and public relation with passengers and operators. An estimated investment of SEK 410 to 450 million would have decreased half of the delay, bringing it to a normal winter situation. (Szafránski, 2011) (Andersson, 2010)

Figure 2. Maps of countries that experienced infrastructure problems (Enno Wiebe, Factsheet root causes, 2010)
The situation in United Kingdom was not better that year with dramatic failure of Eurostar trains in the Channel Tunnel. On December 18 and 19 2009, 2400 passengers were left stranded with four out of five trains saving process turning to chaos. (Smith, Has Eurostar learned the lessons of its winter failures?, 2011) The service was cancelled for the next three days and more importantly, passengers were clueless of the consequence of this shutdown. The year before, heavy snowfall forced the cancellation of many trains on February 2nd, 2010. (David Quarmby, 2010)

![Figure 3](image)

**Figure 3.** Trains running per weekday in England for Winter 2008/09 and Winter 2009/10 (David Quarmby, 2010)

Figure 3 represents the number of trains run per weekday, with a strong service reduction in February 2009 and a longer, yet less deep, reduction in the middle of winter 2009/10.

As seen in (David Quarmby, 2010), the average punctuality of the trains in 2009/2010 under 14 severe weather days was of only 72%, some of the railway operators sometimes achieving less than a third of the standard service.

According to Eurostar (Massey, 2009), the type of snow affected its service in 2009/2010 as the snow was too fluffy and the trains not designed for it. This statement became some source of ridicule but is a confirmed fact. According to (Hood, 2006), the snow coming from the Pacific is dry and light which easily build-ups but is also easily blown away without affecting the operations. The snow coming from the Japan Sea is heavier and wetter requiring an effective sprinkling system.
Szafránski (2011) also mentions that dry snow whirls around the train and cling to it, mostly in the bogies and under frames. “Dry snow builds up in areas such as the bogie, pushes inside the vehicle through e.g. air intakes and also affects disc brakes.” (Lennart Kloow, 2006)

“Examinations show that the most problematic ice crystal for modern transport infrastructure (including railways and their rolling stock and infrastructure) are the needle-shaped crystals, growing at temperatures around -5 degrees, as hollow cylinders with a length up to 1.1 mm.” (Enno Wiebe, Factsheet Snow and Ice, 2010)

Moving in the same direction, NSB and CargoNet confirmed that fine dry snow was the worst for the rolling stock since it gathers in narrow areas. (Haugland, 2011) (Hauglund, 2011) (Eirik Fure, 2011)

![Figure 4. Type of snowflakes depending on temperature and water saturation (Enno Wiebe, Factsheet Snow and Ice, 2010)](image-url)
3.1 De-icing versus anti-icing

As seen in (Enno Wiebe, Factsheet De-Icing, 2010), de-icing and anti-icing are two different ways to cope with ice and snow. “De-icing is the process of removing frozen contaminant, snow, ice, slush, from a surface. Anti-icing is the process of protecting against the formation of frozen contaminant, snow, ice and slush on a surface. (Mainly road and aviation sector)”

Both de-icing and anti-icing can be performed by mechanical, chemical or electrical means. Example for de-icing is the use of de-icing boot, propylene glycol or electrical pulse as for anti-icing, an effective design, the use of different coating or material or the application of a DC bias to change the polarity will reduce ice bonding.
4 ROLLING STOCK TECHNOLOGIES

4.1 Rolling stock design

It is known in engineering that some shape offers better strength or aerodynamic than others. For example, domes and arches are structurally stronger than rectangular shapes and water drop shapes offers less resistance to air than any other shape. The same applies to ice bonding when designing rolling stocks.

When operating at high speed, gap between parts allow vibrations to absorb the energy. When two free parts start moving together, the consequence can range from reduce comfort to derailment if resonance occurs in one of the part. If snow, as dry and fine it can be, get stuck between two parallel flat surfaces, build-ups will occur and eventually create ice. The vibrations will be impeded cancelling the dampening purpose of the gap.

By using a sharp edge surface, snow will still gather up but will break as soon as the tip hits the build-ups. With that design, gaps are more likely to stay free of ice. When designing rolling stocks, rounded surfaces should be prioritised over flat one as they are less subject to build-ups. (Lennart Kloow, 2006)

4.2 Material

Ice adhesion differs from one material to another. For example, ice is more likely to bond to wood than to steel because of its highest porosity. However, metal porosity is not as easy to determine. Research confirms that ice will bond more easily to aluminum than steel because of aluminum higher surface energy. (Susan Frankenstein, June 2002)
Chemical coating can be sprayed on material to change the property and reduce ice bond. The coating can change properties in two different ways; lower adhesion or decrease freezing point, the first one being the most common option. On the one hand, decreasing freezing point presents challenges such as uneven results and difficult optimisation of the amount of chemicals to use. On the other hand, lowering adhesion has been the heart of many material research centres. (Susan Frankenstein, June 2002)

The principle behind low adhesion is to have a really strong bond with substrate material on one side but almost inert on the other side. This will provide a durable non-sticky material. However, low adhesion materials cannot shed ice properly speaking; mechanical and thermal methods are still to be used to shatter the ice. (Lennart Kloow, 2006)

The most spread material used for that purpose is Teflon, a durable non-sticky surface. Other tested materials are silicone, rubber and neoprene. However, none but one material had a lower adhesive surface on ice than Teflon; substances that contain polysiloxanes. The drawback of the use of coating on rolling stock is its durability and difficulty to spray on the parts. Moreover, some parts cannot be coated at all, for example brakes. (Susan Frankenstein, June 2002)
4.3 Mechanical
The mechanical method implies that a force is applied to the ice breaking it and eventually making it fall off the rolling stock. It can be done manually or by an automatic system. However, the manual method can only be performed while the train is parked and implies an operator. This option is not viable for the industry.

The airplane industry also has to deal with ice to avoid irreparable accident. An efficient method to remove ice from the wings is the use of de-icing boots. Invented in the 1920’s, de-icing boots consists of a thick rubber membrane installed over areas most likely to accumulate ice. When too much ice starts building up on the wings, a pneumatic system inflates the boot shedding the ice. It then returns to its optimal shape. Whereas the system is almost 100 years old, it is still wide-spread in the industry. (Landsberg, 2004) The problem of this system is its durability and its limitation when packed ice starts overwhelming the system. However, the system is seen as a primordial safety system for airplanes while dysfunction on rolling stocks would more likely only lead to delayed service.

This system would be efficient on the rolling stock body to remove ice but this concern is of less importance than on the bogie and brake system. The implementation on those latter systems would be slightly difficult as those parts are complex and a pneumatic de-icing boot would be hard to install.

4.4 Electrical
Three electrical methods can be used when it is time to eliminate ice on a surface; heaters, electric pulse and DC Bias.

4.4.1 Heaters
Heaters have been tested on areas where build up is extra problematic with good result when it comes to melt ice. The system is installed on the parts and melts snow and ice as soon as it touches it. However, two problems arise from this method being high energy consumption and uncontrollable melting water. Energy consumed by the heater
increases the operation cost as the melting water might swirl in another area where it freezes again and causes even more damage. (Lennart Kloow, 2006) (Susan Frankenstein, June 2002)

![Figure 7. Heater de-icing (Lennart Kloow, 2006)](image)

A non-melting and more energy efficient method can replace that system in an efficient way, the electric pulse

### 4.4.2 Electric pulse de-icing

This system is the equivalent of de-icing boots using electric pulse instead of pneumatic hose. By applying short bursts of opposite direction current to two conductors, the wire will push apart. When the wires are covered by a thin, flexible polyurethane elastomer blanket, the built up ice and snow will break and fall off the part. This system uses a lot less energy than the heating system. (Susan Frankenstein, June 2002)

A good way to increase the efficiency of this system is by combining the technology with the use of non-sticky flexible surface. The ice will not tend to gather but in the event of build-up, an active system will break the ice.

### 4.4.3 DC Bias anti-icing

The last electrical method is the use of a DC bias to change the polarity of the steel surface. When a positive pole is activated, the formation of ice was decreasing. Inversely, a negative pole increase ice formation. This is due to the corrosion on the top
layer of the steel sheet decreasing the bonding strength. The higher the current is the lower is the bonding. Two phenomena are seen in this method; bubbles formed by the corrosion produces small cracks breaking ice down and heat generated by the use of DC bias. (Susan Frankenstein, June 2002)

This system coupled with the electric pulse might decrease chances of ice build-up on rolling stock parts. However, aluminum and steel will offer an adhesive strength similar to Teflon and polyethylene when DC bias is used.

4.5 Frozen horns

Simple yet efficient way to avoid this problem to occur again is the use of a sock-like piece of textiles. (Enno Wiebe, Factsheet Frozen Horn, 2010) Trucking industry is using a similar technology with plastic cover to protect air horn from rain, snow, dirt, etc. (Wolo)

![Figure 8. Horn protection cover (Wolo)](image)
4.6 Snow deflector

Once again borrowed from the trucking industry, snow deflectors will reduce the snow particles to settle in the bogie. (Enno Wiebe, Factsheet Snow Deflector, 2010) In Figure 9 the deflector is illustrated as the red part in front of the bogie.

Figure 9 Deflector in front of bogie (Enno Wiebe, Factsheet Snow Deflector, 2010)

Other snow deflectors can be used to enhance visibility while running in powdery snow as seen on Figure 10. under the windshield and in front of the side-window.

Figure 10. Locomotive snow deflector (Brennan, 2007)
Another snow deflector was tested by VIA Rail Canada to avoid blocking access to the rear doors as seen on Figure 11. This technology is a temporary quick fix but might be included in the new VIA Rail winterisation program.

One of the drawbacks of this technology is the reduction of aerodynamic, mostly at high speed.

4.7 Hot air de-icing

ScotRail came up with an innovative way of de-icing a train by using a skirt to keep the heat under the rolling stock as seen in Figure 12. The technology was used in 2010 and believed to be the first time in the rail industry. Kenny Scott, engineer director at ScotRail mentions that “The sub-zero temperatures last week were so low that we have not been able to get enough trains into warm sheds to defrost. However, with the heated skirts we can effectively defrost them while outside a depot - which means trains are back in passenger service more quickly.” It takes about 30 minutes to attach the skirt but the train is de-iced in four hours. (Scott, 2010) Other planned technologies were doubling the number of high pressure water jet and increasing the temperature in the depots.
This technology can be used in countries where winter is not too harsh and short but would turn out to be expensive and inefficient for countries dealing with long and cold winter as in Norway.

4.8 Propylene glycol de-icing/anti-icing

The use of chemical products has not received much attention so far in the railway industry. However, this approach might be the most interesting when dealing with ice and snow melting. This chapter will focus on another technology, the use of propylene glycol.

This thawing method is highly used in the airline industry when it is time to remove bonded ice on the plane while immobile. (Pélougas, 2010) Propylene glycol transfers energy in a better way than water and air making it an interesting fluid to use. De-icing of a train using hot air is highly inefficient both money and time wise. This method can take up to 10 hours while the use of propylene glycol will do the same job in just a minute. “According to our experience, Nordic De-Icing consumes around one tenth of
the energy needed for conventional de-icing, and takes less than a tenth of the time.” (Smith, De-icing solution, January 2009)

Many other means have been used to deice the rolling stock such as hot water and direct flames. However, the first option caused corrosion and the local power utility had to be notified when a train was about to enter the de-icing station. The second option was damaging bearings and other parts.

A new system invented by Thomas Jemt called Nordic De-Icing offers advantages in many ways. First of all as mention previously, it thaws snow and ice on a wagon in less than a minute. It is more energy efficient than other method such as water dicing or hot air blowing by using a maximum of only 100 kW on full power while completely fitting on a truck and taking just a day to install. Concerns might arise concerning the environmental-friendliness of propylene glycol but according to (Lennart Kloow, 2006) “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.” (Smith, De-icing solution, January 2009)

Figure 13. Systems in operation by SJ, the Swedish national operator. (Jemt)
In that effect, the propylene glycol is not wasted but collected to be filtered from oil and heavy metal. The filter is then sent for destruction once a year, one of the only maintenance required on the system combined apart from a mere 20 additional minutes per week. With this system, the propylene glycol is virtually completely recycled, the residual part staying on the rolling stock providing long lasting anti-icing solution. (Smith, De-icing solution, January 2009)

Figure 14. The system sprays de-icing liquid and recollects it (Jemt)

The benefits of this technology are multiple according to Nordic GSE, the company behind the system: (NordicGSE, It will be winter again - Do you want to risk this?)

- Prevents ice build-ups
- Environmentally friendly - reduces significantly the need for energy-consuming de-icing
- Fast, efficient and fully automated operation
- Recycles and purifies the liquid
- Customized for various train types
- Easy to install in both existing and new infrastructure
- Can be placed outdoors – no need for expensive buildings
- Advanced software for monitoring and control
- User-friendly
Two companies’ statements prove the efficiency of the technology and their satisfaction towards it.

The Finnish National Railway (VR) started using the system on January 4th, 2011 to deice local and long-distance trains, including the high speed train Pendolino. (Adler, Nordic Anti-Icing Delivered to Finnish State Railways, 2011) That same day, Otto Lehtipuu, Environmental and Public Relations Director and Ari Vanhanen, Long Distance Traffic Director respectively stated in local newspaper their satisfaction: (Jemt)

“VR trains have been better in keeping their schedule then last year and we expect the situation to further improve due to the anti-icing system installed”, Lehtipuu

“Before we have had to use warm water or air and a lot of energy to de-ice trains – this is a considerable improvement” Vanhanen

The NSB service company Mantena acquired the system in 2005 in order to treat the train with an anti-icing coating. The operation is performed weekly as a preventive treatment throughout winter season. In case of important ice build-ups, the system is also used as a de-icer. According to Tommy Thygesen, technical manager of Mantena, the advantages of the system are: (NordicGSE, It will be winter again - Do you want to risk this?)

“• In general, ice problems have been decreased by 50 percent.
• The amount of ice on a normal train set has been reduced by 50-60 percent.

• The amount of ice on a heavily iced train has been reduced by 60-70 percent.

• The ice comes off easier: It takes less than half the time.

• The need for de-icing has been sharply reduced: 60 percent fewer trains need to be de-iced.

• Faster de-icing: with anti-icing treatment, eventual de-icing takes less than half the time.”

Moreover, the Nordic De-/Anti-Icing system has been delivered to Green Cargo (NordicGSE, Media, 2010) in November 2010 and to Jernbaneverket in March 2011. (Adler, Nordic Anti-Icing Cargo delivered to Jernbaneverket, 2011)

4.9 Pantograph protection
The pantograph is a really fragile part of the train as it is made of a carbon strip. During winter, the contact wire is likely to be covered with ice due to freezing rain or other precipitation. In case the pantograph hits a piece of ice, the impact might damage the carbon strip. Moreover, if the pantograph loses its connection with the contact wire, an electric arc will be produce possibly increasing the temperature to 3000°C. This thermal
shock is likely to damage the carbon strip and wear it prematurely. Multiple solutions have been proposed to deal with this problem.

A solution is to have thicker, thus more resistant carbon pantograph during winter. Another one is to use aluminum instead of carbon or to use a 20 mm thick brass strip in front of the carbon strip. As used in Stockholm local trains running at low speed (20 – 50 km/h), a roller covers the wire with propylene glycol instantly removing any snow or ice. (Szafránski, 2011)

A system was implemented to avoid damage to the pantograph named auto-drop device (ADD). In case the pantograph is damaged, the ADD lowers it to avoid further damage to the contact wire or the pantograph itself. This way, only the contact strip will be damaged instead of the whole pantograph or worst, the whole network occasioning important delays. (Szafránski, 2011) (Managers, 2009)
5 INFRASTRUCTURE TECHNOLOGIES

5.1 Sprinklers
The use of sprinklers to melt down ice and snow is not spread around the world considering the need to warm up water to achieve it. However, sprinklers have been used in Japan since 1966 in order to avoid damaging rolling stock and reduce undesired delays. (Lennart Kloow, 2006) (Toshishige Fujii, 2002) (Hood, 2006) With annual snowfall of more than 200 cm and temperature as low as -20°C, the Joetsu line is Japan requires reliable and effective technology to deal with snow. (Hood, 2006) Other Japanese line also requires this system but on a smaller scale as seen on Tohoku line. Joetsu sprinklers are used on 76 kilometers as the Tohoku line system is on a 3-kilometer section. The sprinkling system spreads hot water on the track, recollects it and heated again to be sprinkled once more.

Figure 17. Outline of a Japanese water sprinkler melting system (Lennart Kloow, 2006)
To melt that snow, which can consist of more than a metre of snow in a day, the system needs to sprinkle a humongous quantity of water. The capacity of the Joetsu sprinkling system is of 0.77 litres of water per square metre per minute, the equivalent of 42 mm of rain per hour. (Hood, 2006) However, the most important sprinkling system is used on a 3-kilometre section of the Tohoku line with the equivalent of 73 mm of rain per hour. As mentioned in (Hood, 2006), the use of the sprinklers on the Tohoku line is not as frequent as on the Joetsu line but the use of concrete slabs instead of ballast increase snow accumulations.

Even though the system is highly effective on some lines, it lacks of control on others. It is stated in (Toshishige Fujii, 2002) that the system is not as effective as expected. For example, on Tokaido line, the trains might be required to reduce speed down to 70 km/h to avoid flying ice and snow. However the system is based on the driver’s evaluation of the track conditions which often lead to significant inadequate delays.

However, on the first operating year of the Joetsu line, only one train got cancelled and hardly any delayed. (Hood, 2006) The investment required for the installation is however important as well as the running cost. This represents $11 million in 2000 for Joetsu line (Hood, 2006)
5.2 Slush-mixture pumping system

Similar to the previous technology, the slush-mixture pumping system has been installed in Japan for the first time in 1983. The system mixes water to the snow cleared from the tracks in the nearby gutters. The tracks cleaning requires only six workers compared to 50 people and a whole day before the use of this technology.

The technology behind the system is to clear the track with a conventional rotary snow removal train and drop it in the nearby gutters. Pumps bring water from the nearby river at a rate of 5.2 tons per minute. Additionally, a water tank is filled with water able to provide up to 10 tons of water per minute for a combined 15.2 tons per minute. The snow and water form a sherbet-like slush carried down the gutters and pump away to the nearby river. The system is highly efficient as “5.2 tons of water and 1.05 tons of snow come gushing out of the discharge outlet every minute. The remaining water that passes through the filter is circulated back into the water storage tank.” (Yokota) (Juneau)
5.3 Chemical de-icing

In (Smith, Beating the chill, January 2011), Dr Foster Ross reveals Kilfrost technologies that can overcome problem with frost, snow and ice. It mostly deals with snowy and icy platforms but also with third rail anti-icer. The chemical products are specially developed for the rail industry where products have to be effective in sub-zero temperature without high electrical conductivity to avoid short circuit.

“Kilfrost Rail is designed to offer protection on the rail for extended periods, prevent ice forming on the rail, offer resistance to snow, rain and hail, and help trains to operate in temperatures of -25°C and below” (Smith, Beating the chill, January 2011)

5.4 Snow fence

A good way to avoid snow accumulation on the tracks is to carefully design the tracks and its surrounding. For example, a fence reduces the snow drift on track by decreasing the speed of the particles, thus stopping the snow from going forward. (Tabler, 1991) Moreover, when snow ploughs are used, cuttings are needed in order to keep the snow off the track.

As seen in (Lennart Kloow, 2006), the design of tracks’ surroundings is important to keep the snow off the track. The use of avalanche fences in mountainous areas prevents catastrophic scenarios. Combined with avalanche protection forest, the impact on the environment is reduced by keeping a natural landscape around the track. High-risk avalanche areas uses avalanche deflecting structure in order to slow down the
avalanche with an angle, reducing the force applied on the wall. Snow sheds and tunnels also reduce the quantity of snow gathered on tracks. Most of those structures can be added to the tracks’ surroundings without interrupting trains services and at a fairly low cost.

By using a snow fence next to the tracks, wind loses speed and energy making suspended snow to rest. It causes a small upwind drift and a large downwind drift next to the fence. (IDT, 2005) (Ramstedt, 2011) Fences can be permanent structure or living trees, shrubs or native grasses. As mentionned in (IDT, 2005), the advantages of snowfences are:

“Public benefits of snow fence

- Reduces blowing and drifting snow on railways
- Stores snow at low cost
• *Reduces the accident rate during snowy, windy conditions*

• *Creates safer travel conditions*

• *Decreases freezing and thawing effects on the railway*

• *Lowers snow removal cost*

• *Increases visibility*

![Figure 23. Expected snowdrift while using a snow fence (IDT, 2005)](image)

An important thing to take into account when using a fence is that the ends of the fence extend 30° beyond the protection limits. This ensures a complete protection of the tracks. Porosity is best at 40% to 50%. (Tabler, 1991)
The previous examples are for roadways but the same can be applied to railways.

According to (Szafránski, 2011), afforestation is the best solution for snow fences but can be swap to permanent snow-retaining barrier in case vegetation is impossible to grow. Mobile snow barriers should be used as temporary measure while building permanent barriers or to increase the capacity of a permanent barrier for a certain period.

As discussed with NSB and CargoNet (Haugland, 2011) (Hauglund, 2011) (Eirik Fure, 2011), fences are highly used in Norway but mostly on the Oslo-Bergen line where snowdrifts are really important in this near-Arctic conditions.

Moreover, both companies experience problem when it comes to medium-sized tunnel. During winter, the problem resides in the high temperature gap in and outside the tunnel. A short tunnel will not affect the train on a period long enough and a really long tunnel might, in some case, melt away enough snow to thaw it completely. However, in mid-sized tunnel, the packed snow will partly melt, producing wet snow that will gather dry snow when it exits the tunnel. With the speed of the train and the sub-zero temperature, the packed snow will rapidly turn to ice, increasing the weight of the rolling stock and increasing the risk of blocking switches with ice breaking away. (Hauglund, 2011) (Haugland, 2011) (Eirik Fure, 2011) (Szafránski, 2011)

5.5 Larger cuttings

One of the main problems during wintertime is to find a place to get rid of the snow. In most countries, snow accumulations are not of enough importance to encounter problems. The snow ploughs can simply push the snow on the side of the track. However, when important snowfalls occur or winter last for a longer time, more room has to be allowed for snow clearing. As mentioned in (Lennart Kloow, 2006), designing tracks with larger cutters will prevent snow from being packed next to the track.
5.6 Viaducts

Another way of dealing with snow storage area is the use of viaducts. Toshishiga (2002) presents the plans of a viaduct that could be used for winter conditions. The motorcar rotary blows the snow between two walls. The inner wall has noise barrier function as the outer wall guides ejected snow ejected by the motorcar rotary. With that type of infrastructure, snow storage is a problem of the past.
5.7 Railroad switch heaters

Railroad switches is one of the system needing most attention during winter time. Since switches are lying on the ground, snow and ice will always gather up, thus blocking the system. Heating systems have been use for more than 60 years to cope with that issue but never evolved. Those heaters can use up to 20000 kWh, the consumption of a normal size house. With over 150000 heated railroad switch in Europe, development of a new technology is primordial.

SwedeSafe, a Swedish company specialised with solutions to keep surfaces free of snow and ice applied its technology to the rail industry. The system is 50% more energy efficient than the high temperature hot water piping or heating cable. (Enno Wiebe, Factsheet New Heating System, 2010) The technology used is simple yet efficient. “The plates are supplied by 48V electricity. They are connected in parallel in groups of 2-5 units. The temperature of each unit is controlled individually by a sensor/transmitter connected to a control unit. The controller unit guaranties that proper power is delivered to each plate.” (Ohlsson) The energy consumption per unit is of the scale of 150-180 W per square metre.

Figure 27. Technology behind SwedeSafe (Ohlsson)
Another simple way to avoid switches to freeze is to heat the space between the rails and not the rail itself. (Ramstedt, 2011)
As seen in Figure 30, the length of the wire can be shorter than the rail itself as the warmth is transferred by conduction to a longer part of the rail.

Finally, cameras and sensors are now being installed in Oslo area to permanently keep an eye on the switches. Combined with more powerful switches, the infrastructure managers are able to turn on the heaters when needed and send a team to clean the switch in case the switch cannot melt or break the ice. (Haugland, 2011) (Hauglund, 2011) (Eirik Fure, 2011)

5.8 Railroad switch design

Combine with switch heater, an appropriate railroad switch design can keep snow and ice off the track. By insulating the switches with plastic and wooden cover, heat remains on the track for a longer period. (Enno Wiebe, Factsheet Switches and Crossing, 2010) According to (Ramstedt, 2011) this technology is suitable for speed equal or lower to 160 km/h.
Both NSB and CargoNet agreed that Oslo Central station was the most important hub in Norway and that improvement were to be made to ensure a complete reliability during winter. For example, future renewal of the switches by Jernbaneverket in summer 2011 is seen as an important improvement.

5.9 SnowProtec brushes

By using brushes next to the switches, trains create an airflow clearing snow from the rail. This new technology developed by Osborn International AB has been tested on the new Bothnia line in Swedish in collaboration with Banverket (Swedish National Rail Administration) and introduced as standard of Banverket. (Smith, Has Eurostar learned the lessons of its winter failures?, 2011)
“SnowProtec Brushes are simple yet extremely effective. The product consists of brushes assembled upwards and downwards on the outside of the support rail all along the switch tongue’s movable part. The brushes provide a very effective protection against snow-drift and at the same time aids the retention of heat from the pre-warmed switch on the rail. The result is snow free switches, considerably simpler handling, more economic, and above all operation safe – both on conventional and high speed tracks.” (International)

As seen in (International), Raimo Kajén, track engineer for Banverket is highly pleased with the system. “From the beginning I was certainly sceptical to the technology, but after reviewing the evaluation results taken over the last 3 years - I really can see the obvious benefits.”
The advantages of the system are numerous. It partly protects the rail from snowdrift but most importantly, clears the rail when a train is passing by. Brushes have a long life span, require only little maintenance and dismantling is unnecessary even for snow sweeping with brush machines. The brushes can be used for speed over 160 km/h, making it a cheap yet efficient solution for high speed trains. (Ramstedt, 2011)

Moreover, installation is fast with approximately two hours for installation. (International)

5.10 Dry ice blasting

In case manual clearing has to be used, dry ice blasting is recommended as it leaves a surface perfectly clean (Figure 34) compared to the use of a broom. “Dry ice blasting cleans in-situ without disassembly or cool down and is non-abrasive, non-conductive, non-corrosive, and does not use water. It is a completely dry and clean process. The perfect cleaning method for trains, train parts, tracks (rail) and associated equipment.” (IceTechServices, 2009)

![Figure 34. Uncleaned and cleaned rail with dry ice blasting (Ramstedt, 2011)]
6 WINTER OPERATIONS

Even with the best technologies, Mother Nature will always disturb human activities in some way. In case of important snowstorms where the previous technologies are overwhelmed, it is imperative to be prepared and have the taskforce ready. This chapter will describe what changes should be brought when an important snowstorm is incoming.

In most of the operation procedures, communication between the weather forecasting group, the infrastructure manager and the train operators is the key to success. The weather forecasting group needs to alert the companies that an incoming snowstorm is about to hit the railway network and to stay in standby to be ready to react. Experience and lesson-learnt will allow all the involved companies to deal with winter in the future.

6.1 Winterisation

As seen in (Smith, Has Eurostar learned the lessons of its winter failures?, 2011) problems occurred in the Channel tunnel with Eurostar trains. An inadequate winterisation program combined with overwhelming snowstorm and human errors caused five trains to be delayed. In 2010, a new revamped winterisation programme was set to avoid a major breakdown in the tunnel. Much more inspections and improved communication allows Eurostar to deal with winter conditions as soon as it appears. For example, alternative cross-channel routes are rapidly set with P&O Ferry in the even that trains are cancelled. Also, cameras were installed in case real-time information is needed. (Smith, Has Eurostar learned the lessons of its winter failures?, 2011)

Another winterisation program is based on ex-USSR experience. The program is mostly applied to the infrastructure but also relates to the operation. Safety seminars are attended by signalling technicians in August-September. Neophyte workers of all sorts are also summoned to attend the presentations. (Szafránski, 2011)
In September-October, inspection of the signalling and telecommunication system is performed. Every hotbox detectors, marshalling yards and technical structures are inspected. Cabling and spare parts receive a special attention. It is also the time of the year where the technical rooms are refurbished and resupplied with spare parts and fuel. (Szafránski, 2011)

During fall, outdoor equipment are also cleaned from all accumulated dirt and greased again with proper winter lubricant. Sealing are also changed to winter sealing made of oakum as they are not as affected by cold as rubber. (Szafránski, 2011)

At the end of the winter, a detailed check of all the signalling and telecommunication devices is performed and defects noted. The problems will later be fixed and improvements will be implemented to avoid them in the future.

Finally, landmarks are used where snow ploughs might damage outdoor sleeves or boxes. Relay cabinets should also be positioned far enough (three to four metres) from the tracks and on raised base to avoid burying them with snow and damaging them. (Szafránski, 2011)

The complete USSR winterisation program is described in chapter 2.3 of Szafránski (2011) “WINTER AND RAILWAYS – STUDY”.

The winterisation program of both NSB and CargoNet begins by December of each year but is adapted depending of the weather forecast. Winterisation consists mostly of adapting the maintenance program to winter by treating the rolling stock with propylene glycol and checking the delicate parts more often, for example the pantograph. The propylene glycol treatment is not yet fully applied for the freight companies in Norway but is likely to be fully operative in 2011/2012 as Jernbaneverket acquired the system in March 2011. The treatment is generally to be performed each other week but increases in case of higher precipitations. (Hauglund, 2011) (Haugland, 2011) (Eirik Fure, 2011)
6.2 Joint operation centre

Communication between infrastructure management and railway undertaking is primordial during crisis. Germany, France and the Netherlands set up a joint operation centre where real time decisions can be done regarding traffic on the network. It allows them to make better decision in order to provide the best for every customer. In other countries, infrastructure management might have the monopoly of the decisions. In the end, it is in every railway-related company’s interest to have a reliable service and network. (Szafránski, 2011)

6.3 Extra rolling stock

During winter time, train operators should rely on more rolling stock to ensure proper maintenance. Indeed, maintenance in winter conditions takes more time to deice the trains or to perform the maintenance itself. Even though propylene glycol de-icing can take less than a tenth of conventional de-icing, extra rolling stock is needed in case of de-icing malfunction. Moreover, in case of freezing cold temperature, even proper de-icing might not be enough to unfreeze the wires and hydraulic system. Keeping the extra rolling stock warm and ready in a hangar will avoid any unwanted situation.

Procurement of new snow ploughs might not be profitable in the long term as harsh winter occurs on average triennially (Haugland, 2011) and they can be used only during winter season. However, in 2009/2010 winter crisis, DSB Museumstog lent its operational museum locomotive MY1101 to Denmark’s infrastructure manager DSB. It played a key role in keeping the Danish network functional even though the locomotive was more than 45 years old. Norwegian railway museum also owns two identical MY1101 in running order which could be used in a future to clean tracks in case of important snowstorm. (Szafránski, 2011)

Similarly, in Switzerland where harsh winter occurs once or twice every ten years, steam-powered rotating snow ploughs are occasionally used. As mentioned in Szafránski (2011), not only will it increase cleaning capacity, it will show the general public that the infrastructure manager will use whatever works to run an operative network.
6.4 Extra personnel
During winter season, extra personal should be assigned in case of snowstorm. These employees placed on a waiting list are ready to be called to job anytime when a snowstorm is underway.

During winter, switches are highly subject to freezing and blocking due to packed snow coming off the train. The heaters are of great help to avoid problems but when a snowstorm is overwhelming, manual cleaning is required. In this case, the infrastructure manager should have the required workforce available. (Szafránski, 2011)

This system is used in other industries where extreme temperatures impede normal operations, for example aluminum smelters where extreme heat force a higher rotation of personal. Applied to the train industry, this system would ease workers job having a backup worker and increasing efficiency.

An option proposed by UIC (Szafránski, 2011) is to let administrative people work on the field. This solution is highly improbable knowing that unions would not allow this scenario but worst case scenario, this option could be considered. This solution would also give a valuable image to the railway company proving they would do everything they can to fix winter problems.

According to CargoNet, more workers are needed during winter because of absenteeism and it might decrease the efficiency of the cleaning of the switches. However, by improving the actual switches, the need of more workers will be reduced.

6.5 Extra warehouse
One of the problems caused by winter is the exposition of the rolling stock to sub-zero temperature and snow over a long period of time. This exposition increases the corrosion and stress of the parts. A proposed solution is to increase the number of warehouse to protect the wagons and locomotives from the outdoor harsh weather. Semi-heated warehouse would be adequate for this purpose, the goal being to avoid parts from freezing. (Haugland, 2011)
6.6 Iced couplings

As seen in (Enno Wiebe, Factsheet root causes, 2010) couplings were one of the most important problem encountered in winter 2009/2010 in Europe. For example, Norwegian trains experience problems when coupling the trains together with hardened grease in cold temperatures.

Solutions to the problems were given in (Enno Wiebe, Factsheet Iced Couplings, 2010) ranging from reduced traffic, a less recommended action, to avoiding coupling in normal traffic, preferably doing it at a maintenance depot where it is warm and technical assistance is readily available.

A third solution, and best solution, was to avoid or reduce couplings by using shorter train formations. The benefits were as follow: (Enno Wiebe, Factsheet Iced Couplings, 2010)

“a.) Suspend splitting and joining services during snow. Winter extreme weather plan to formalise the cessation of splitting and joining services during extreme weather

b.) Minimise coupling events. Although running separated rail car formations will increase the maintenance costs and track access charges, the risk of overcrowding and leaving passengers behind on freezing stations was almost eliminated.

Cancellations and delay minutes were kept to a minimum.”

6.7 Severe European Weather Management

As seen in (Arnold, 2010) presentation, a European-wide weather management site would improve communications between participating countries thus increasing useful information sharing. Started in February 2008, the Network Rail Seasons Management Team weather (SMTWeather) was implemented after high wind severe weather in 2007 with a Google Map interface, conductor rail forecasting and an archive database.
In 2009, MeteoGroup joined SMTWeather providing fully integrated weather forecasting with national forecast, rail freight wind warning, route information, etc. The idea was to have an embedded process across UK rail industry. (MeteoGroup, 2011)

In September 2010, the International Union of Railways decided to be interested in the project and asked Arnold to further development of a European Severe Weather Management & Communications. Improvements would include the list of key operating personal contact, recognised supplier contact and prompt actual weather data from shared weather stations. (Enno Wiebe, Factsheet Weather Management, 2010)

A quadrant of aims depicts the future action of the new European Severe Weather Management & Communications tool.

![European Severe Weather Management](image)

**Figure 35. European Severe Weather Management (Arnold, 2010)**
### 6.8 Winter preparation

Developed by Deutsche Bahn AG, a table was made for winter preparation according to the severity of the snowstorm. The original version is in German, here translate to English. (Enno Wiebe, Factsheet Winter Preparation, 2010)

<table>
<thead>
<tr>
<th>Table 1. Winter preparation developed by Deutsche Bahn AG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weather</strong></td>
</tr>
<tr>
<td>Slight to moderate snowfall</td>
</tr>
<tr>
<td>No or little snowdrift</td>
</tr>
<tr>
<td>Sparse ice formation (Freezing rain, snow, ice, frost)</td>
</tr>
<tr>
<td><strong>Operation</strong></td>
</tr>
<tr>
<td>All systems are to be kept functional</td>
</tr>
<tr>
<td><strong>Usage</strong></td>
</tr>
<tr>
<td>Under circumstances, usage of snow ploughs</td>
</tr>
<tr>
<td>Under circumstances, replacement of the leading vehicles</td>
</tr>
</tbody>
</table>
6.9 Reduced service plan

The idea behind a reduced service plan is to set the railroad switches to a certain position prior to a snowstorm. Priority should be given to the early departures followed by the busiest and most important routes. Less operations are needed thus decreasing the chances of malfunctioning. (Enno Wiebe, Factsheet Reduced Service, 2010)

<table>
<thead>
<tr>
<th>Linje</th>
<th>Södra Stambanan, Mjölbry - Malmö</th>
<th>Snöberedskap 3</th>
<th>Snöberedskap 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mjölbry) - Tranås</td>
<td>Tranås, vxl 101-103, 105 o 106</td>
<td>Boxholm, Sammen</td>
<td></td>
</tr>
<tr>
<td>(Tranås) - Näsjö</td>
<td></td>
<td>Fnnaryd, vxl 105, 106, 135, 136</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gamlarp, Vinnarp vxl 132</td>
<td></td>
</tr>
<tr>
<td>Näsjö</td>
<td>vxl 405-409, 487-490, 551, 553</td>
<td>Övriga vxl</td>
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<tr>
<td></td>
<td>vxl 557, 558</td>
<td></td>
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<tr>
<td>(Näsjö) - Stockaryd</td>
<td>Stockaryd</td>
<td></td>
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<td>(Stockaryd) - Alvesta</td>
<td></td>
<td>Grevaryd</td>
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</tr>
<tr>
<td>(Alvesta) - Almhult</td>
<td>Vislanda, Almhult</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Almhult) - Hassleholm</td>
<td></td>
<td>Osby vxl 31 o 32</td>
<td></td>
</tr>
<tr>
<td>Hassleholm</td>
<td>vxl 463, 464, 473, 474, 512-514</td>
<td>vxl 405-408, 461, 452, 465-472</td>
<td></td>
</tr>
<tr>
<td></td>
<td>vxl 475, 476, 552-556</td>
<td>vxl 405-406, 413-414, 478, 480</td>
<td></td>
</tr>
<tr>
<td>(Hassleholm) - Hör</td>
<td></td>
<td>Tornhill vxl 31-32</td>
<td></td>
</tr>
<tr>
<td>Hör - (Lund)</td>
<td>Hör, vxl 21 och 32</td>
<td>Stehag, vxl 31-32</td>
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<td></td>
<td></td>
<td>Eslov vxl 405, 406, 413-414, 478, 480</td>
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<tr>
<td></td>
<td></td>
<td>Tornhill vxl 31-32</td>
<td></td>
</tr>
</tbody>
</table>

Figure 36. Reduced service plan in Sweden (Enno Wiebe, Factsheet Reduced Service, 2010)

In Figure 36, the middle column shows the name of the switches with the highest priority as the one on the right shows the ones with less priority. In case of snowstorm, the managers will start with the high-priority switch before moving with the less important one. For example, international services should prioritise over local service as they will greatly influence operations on several national networks. (Szafrański, 2011)

![Service & Out of Service Diagram](image.png)

Figure 37. Example of reduced service plan (Enno Wiebe, Factsheet Reduced Service, 2010)
6.10 Emergency timetable

As seen in (Enno Wiebe, Factsheet Emergency Timetables, 2010), an emergency timetable could reduce the impact of a snow day. The ADVD (Alternatieve Dienstregeling Volgende Dag or Alternative Timetable Following Day in English) allows dealing with it. The first decision is made 30 hours prior to an incoming snowstorm, starting to plan a timetable for rolling stock, personnel and travel information.

Figure 38. Procedure for the emergency timetable (Enno Wiebe, Factsheet Emergency Timetables, 2010)

As seen in (Enno Wiebe, Factsheet Emergency Timetables, 2010) “Basic philosophy is to eliminate the possibility of getting a chain reaction of delays, by only operating direct trains between mayor nodes. Only the main connections will be ‘Intercity’ all others are only ‘comuter trains’ (= all station stops).

- Limited use of switches, limited use of rolling stock.
- Limited Intercity service (Figure 39)

Figure 39. Example of emergency timetable (Enno Wiebe, Factsheet Emergency Timetables, 2010)

The impact will be negative compared to a normal day but will decrease the effect of the snowstorm on the customers. The average travel time increases by 9 minutes which is 22%, the average “time to next train” by 24% and average time for changing trains by 22%.
The impact on the customers is as follow:

Table 2. Impact on the customers for ADVD

<table>
<thead>
<tr>
<th>Delay</th>
<th>Percentage affected (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No delay</td>
<td>15</td>
</tr>
<tr>
<td>Less than 5 minutes</td>
<td>50</td>
</tr>
<tr>
<td>About 15 minutes</td>
<td>25</td>
</tr>
<tr>
<td>More than 30 minutes</td>
<td>8</td>
</tr>
<tr>
<td>More than 60 minutes</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 40 depicts the percentage affected by the implementation of the ADVD.

Figure 40. Percentage of customers affected according to the extra waiting time (Enno Wiebe, Factsheet Emergency Timetables, 2010)
Here is an example of the ADVD: (Enno Wiebe, Factsheet Emergency Timetables, 2010)

**October 8th**

Situation: A bad weather forecast is released by the weather office, inducing drop of availability of assets (prognosis).

Line of Duty 1 (Alertness): Our operational organizations are warned

Line of Duty 2 (Alternative plan): The decision to prepare ADVD is made

**October 9th**

Situation: Weather forecast becomes realistic. Decision to fully load ADVD is made (deadline 4 PM).

Line of Duty 3 (Steering and Travel Info): Loading of ADVD starts at night and takes until 12 PM

**October 10th**

Line of Duty 4 (Customer Care): ADVD is actually executed. In situation travel occur too much discomfort from this timetable they will be compensated.

**October 11th**

Line of Duty 5: Return to normal schedule after the snowstorm.

“The industry's definition of punctuality is based on commuter services operating within five minutes of the timetable and for longer distance trains, 10 minutes. “ (Millward, 2009)

According to that definition, about 65% of the trains will be punctual using that system. This is higher than what South West Trains experiences with their Snowplan.

“SWT have developed a pre-planned contingency timetable called ‘Snowplan’, which is based on a reduced hourly service pattern and the withdrawal of service from some
minor routes to avoid points being moved on main lines. Snowplan was, however, only used once on 6 January, when 34% of the service was run at 50% punctuality. Without ‘Snowplan’ on the following day, performance fell to 24% of trains run, with only 11% on time.” (David Quarmby, 2010)

6.11 Organisational framework of actions

In order to be ready to deal with an emergency situation during winter, the following organisational framework of actions was implemented by UIC. (Szafránski, 2011) The plan is to be applied from November until February but should be extended for the Nordic countries such as Norway and Sweden.

1. Identify the weather condition
2. Notify the emergency service, both internal and external
3. Mobilise the resources for possible intervention
4. Inform the passengers for the possible inconveniences caused
5. Control trains transiting in this area
6. Coordinate the workforce for the next 24 hours
7. Design of an Alternative Transportation Plan in accordance with the indications and the Infrastructure Manager

Every area affected by the incident should have a local responsible to communicate with the Infrastructure Manager. Depending on the severity of the incident, the local responsible might be replaced by the emergency services. The Infrastructure Manager should follow these recommendations when normal service cannot be met.

- Prioritise passenger trains and dangerous goods
- Inform the operators of possible alternate route
- Examine the cancellation of frequent services
- Delay the train departure to avoid en route stop

The plan is to be updated frequently to take into account previous experience and the availability of technical and human resources.
6.12 Alternative Transportation Plan

The alternative transportation plan is a plan adopted to get all the passengers to their final destination despite the drawback it occurs. As discussed with NSB (Haugland, 2011), the passenger train operators prefer to use an alternative transportation to get their customers to destination rather than having them waiting in the train station. Moreover, they would rather send passengers by bus on a long-distance trip, e.g. Oslo-Trondheim as it will affect fewer passengers as there are only three daily trains serving this corridor. The main hub is the main priority.

For the freight train operators, an alternative transportation plan is hard to implement because of the harsh competition between trucking and freight train industry. Such plan would send a message to customers that trucks might be more reliable than trains, an obviously undesired effect. (Eirik Fure, 2011)

The Alternative Transportation Plan gives options to the train companies to redirect the passengers to their final destination. The trafficking part of the plan is to deal with the train traffic by cancelling part of the service, using another rail alternative or redirecting passengers to another station. The logistic part consists of using alternative traction such as diesel.

In case of a big snowstorm, the infrastructure manager and train operators should be ready to redirect customers to alternative transportation system such as buses or taxis. The station should have a parking lot big enough to allow the alternative transport to park. Customer assistance should be highly available over phone and internet to provide the information to the customers. Emergency blanket should be available on request in case of intense cold or long waiting time.

At the station, the information service should be updated frequently to inform the passengers of any development in the situation.
7 ANALYSIS

7.1 Passive versus active protection

Fire protection can be distinguished between active and passive. The active protection consists of items and/or systems which require motion and response in order to work. Oppositely, passive protections uses materials or specific design to either stop or slow down snow and ice build-ups on the surface.

Most of the passive technologies require low or no maintenance as they are without movable parts. Oppositely, active protection requires movement or heat in order to work increasing the risk of defect and the operational cost.

<table>
<thead>
<tr>
<th>Table 3. Comparison of passive and active technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Passive</strong></td>
</tr>
<tr>
<td>Rolling stock</td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Surface design</td>
</tr>
<tr>
<td>Propylene glycol anti-icing</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Infrastructure</td>
</tr>
<tr>
<td>Snow fences</td>
</tr>
<tr>
<td>Avalanche fences</td>
</tr>
<tr>
<td>Railroad switch design</td>
</tr>
<tr>
<td>SnowProtec brushes</td>
</tr>
<tr>
<td>Larger cuttings</td>
</tr>
<tr>
<td>Viaduct</td>
</tr>
</tbody>
</table>
7.2 Efficiency and price comparison

In order to get a quick overview of the different technologies available and their likeliness to be used in the industry, the following quadrant compares the efficiency to remove or avoid snow with the investment required for the technology.

According to NSB and CargoNet, use of heaters on the rolling stock is expensive and has not proven a high efficiency because of the melting water swirling in another area causing more damage. NSB and CargoNet are reticent in using this technology making it as unviable for the industry. The same applies to all the technologies on the lower-right side of the rolling stock quadrant.

The use of propylene glycol de-icing is getting more and more important and the investment cost is considered as low as the system can be shared by different companies, reducing the cost of them.

Some technologies are likely to be cheap but only if it is integrated in the construction of rolling stock, for example with the surface design. According to NSB and CargoNet, changing the coating could be slightly interesting but the results would not be that important, mostly with the new anti-icing treatment with propylene glycol.

The hot-air de-icing is also an interesting technology for some areas like Scotland but this solution would not be suitable in Norway as many trains need to be de-iced over the year.
As discussed with NSB and CargoNet, the investment for SnowProtec brushes is low and the capacity to protect the track from snow is high. According to them, the brushes are an interesting technology to be used in the industry. Fences are also highly used in Norway to prevent snowdrifts and avalanches. Those two technologies are highly viable for the industry. On the other side, viaducts and larger cuttings can be expensive to build if Jernbaneverket is not planning to modify or build new tracks. However, in the future, this technology should be considered when planning on building new tracks.

The sprinklers and slush-mixture pumping system did not yield the enthusiasm expected as it was seen more likely to cause more problems than solving it. As mentioned by CargoNet and NSB, this technology might be suitable for Japan where snowfall occurs in a fairly mild environment compared to Norway. The sprinkled water would happen to freeze before it even touches the tracks in some Norwegian regions. As for the slush-mixture system, snow in Norway has to be cleaned before deposited in area where it can contaminate water. (Heidenreich, 2007)

Even though railroad switch heaters are expensive to run, they are primordial for infrastructure manager to have a network going smoothly. As mentioned previously, Jernbaneverket will change the switch heaters to have more powerful heaters and
activator. Moreover, cameras and sensors will help reducing the operational cost by closely applying the right heat at the right moment.

**Infrastructure**

![Figure 42. Comparison of the investment required for a technology and the efficiency (Infrastructure)](image)

For the operations, the evaluation of the efficiency compared to the investment is harder to provide as they should be adapted and tested before being applied. However, many operations can be categorised even though the results are unknown, for example the weather management considered as expensive to implement but likely to be efficient. The evaluation also includes long-term consequences such as losing customers.

Winterisation can be quite expensive in order to get the trains ready for winter but in the long-term, any maintenance done to have train operating properly in winter will be beneficial. Moreover, winterisation has to be part of the maintenance program; trains require more attention during winter than summer.

More about planning, the Severe European Weather Management system seems really promising even though implementation of the service throughout Europe might be expensive. By sharing information from countries to another in close relation with the
weather forecasting group, every infrastructure managers and rail operators will know what is incoming and if delays are expected from another country.

Extra rolling stock and personnel might improve the efficiency of the operations but the investment is high and the return is quite low. Other methods should be studied before moving on with rolling stock acquisition or personnel hiring. Extra warehouse provided by Jernbaneverket should be considered as mentioned in the interview with NSB as a simple shelter would already decrease the risk of natural hazard on the rolling stock.

The Alternative Transportation Plan should be kept to a minimum for passenger train operators and completely avoided for the freight companies. The mid-term consequences are that the customers will see the trains as a non-reliable mean of transportation. In the case of freight, many customers will simply swap from rail transportation to trucks for winter.

Finally, the emergency timetable and the reduce service plans should be tested to know if it can easily and efficiently be applied to the railway industry.

**Operations**

![Figure 43. Comparison of the investment required for a technology and the efficiency (Operations)](image)
8 CONCLUSION

High speed rail in Scandinavian winter is a fairly new challenge for infrastructure managers and train operators as it was introduced in Sweden in 1990. However, with the overwhelming snowstorms of winter of 2009/2010, a bell rang in Europe proving that no one was ready to cope with winter. Unfortunately, the wrong was already done. With the potential construction of a high speed rail in Norway, the railway industry is better to get ready earlier than later. The objectives of this report are to provide different options – rolling stock, infrastructure and operations – that can be either applied on the actual network or for a future high speed rail network.

In the end, with a deep literature study and interviews with railway industry actors, many technologies were considered as applicable for railway networks. Some of them were to be integrated in the early phase of the planning, others easily added to the existing infrastructure or rolling stock. The following lists contain the technologies that are seen to be integrated in the future for high speed rail network but also for existing network.

Rolling stock

- Propylene glycol de-icing: Undoubtedly the most promising technology brought so far to the rail industry, the propylene glycol de-icing is a cheap and really efficient way to remove accumulated ice on rolling stock as well as protecting it with an anti-icing treatment. This technology is started to appear in many winter city train hubs with many positive feedbacks.

- Surface design: When new rolling stocks are to be designed, manufacturers should consider using sharp edges in area where snow is likely to get packed. The cost related to it prior to the construction is low and the train operators will increase customers’ comfort by avoiding gaps being filled with ice increasing vibrations from one part to another.

- Material coating: In a lesser extent, material coating might be successful but the use of propylene glycol anti-icing makes it useless.
Infrastructure

- **SnowProtec brushes:** Those brushes are the most promising technology offered for the infrastructure along with snow fences. They help reducing snowdrift on the rail as well as keeping the heat from the switch heaters. The investment and maintenance required is low and it has been proven efficient on the Swedish Bothnia Line.

- **Fences:** Largely used by the industry, fences are a cheap way to prevent snow from getting on the tracks. The construction of permanent fences increase the investment on short-term but is beneficial on the long-term, both financially and for the maintenance.

- **Railroad switch design:** By improving the design of the switches, more heat will melt snow and ice away instead of being dissipated in the environment. Simple covers will increase the efficiency without important investment.

- **Railroad switch heaters:** Even though the use of heaters in winter is expensive, they are primordial for the railway industry. However, more efficient switch heaters means lower operational cost by reducing the need of manual switch cleaning and by heating only the required switches with the use of cameras and sensors.

- **Viaducts and larger cuttings:** In the case a high speed rail is built, viaducts and larger cuttings should be considered before the construction phase. It allows the infrastructure manager to clean the track without risk of snowdrift.

- **Sprinklers and slush-mixture pumping system:** These systems might be useful in some countries like Japan but would cause more trouble in Norway where water drops would freeze even before reaching the railway.

- **Tunnels:** The use of tunnels is unavoidable in Norway but they should either be kept as short as possible or with an excellent ventilation system keeping indoor and outdoor temperature as close as possible. This way, the snow will not melt away and gather even more snow when the train exits the tunnel.
**Operations**

- **Winterisation:** Important part of the operations, winterisation remains one of the most efficient way of dealing with winter. By adapting the rolling stock preventive maintenance programme with more inspections, the resulting outcomes will be the reduction of unexpected repairs. Propylene glycol anti-icing should be integrated in any maintenance program and adapted to the weather conditions.

- **Severe European Weather Management:** This new system will be really important in the future by increasing the communication capacity between the weather forecasting groups and the railway industry actors. Integrated throughout Europe, this system would help avoiding the winter 2009/2010 disaster.

- **Reduce service plan:** A plan of action is primordial when a snowstorm is coming knowing that delays are unavoidable. By setting the priorities to selected routes, for example international one, confusion is reduced and information can be channelled to the customers before they get affected.

- **Alternative Transportation Plan:** On the one hand, this plan is the last options for the passenger train operators since it gives a bad impression to the railway industry. However, the main goal of the operators is to carry the customers from A to B. On the other hand, this option is to be avoided for the freight carriers because swapping to the trucking industry would give a bad image to the industry, knowing that the competition is stronger.

- **Extra personnel and rolling stock:** Best case scenario, investing for warehouse, personnel and rolling stock would be a good solution but many cheaper technologies and operation plans should be considered first.

- **Extra warehouse:** Even though a warehouse is expensive to build, having more semi-heated shelters for the rolling stock would be beneficial for the industry, decreasing the damaging effect of snow, ice and cold.
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VII. APPENDIX 1 – LIST OF QUESTIONS

Background

- When is the worst period for train operation, in other words, when does “winter” start? Is it a precise date or it depends of the weather forecast?
- What is the worst winter scenario? For example, does the temperature influences the operation in a greater way than the snowfall or snowdrift?

Rolling stock

- How does the company get ready for winter?
- Did your company experienced winter problems over the years? If yes, when did it happen?
- What was the problem and in which way it affected the operation?
- What was the cause of the problem? Inadequate design, lack of equipment?
- How did you solve the problem both on short and long-term? Was it successful?
- What is the winterisation program of the company? When is it applied?
- Does one of the following technologies would have helped to solve the problem or do you already use it? For descriptions of the technologies, refer to document “Winter problems.pdf”

Surface design: Use of sharp edges on parts of the rolling stock in order to break the ice

Material: Use of different material to lower ice bonding e.g. Teflon or Plexiglas

Heaters: Use of heater in areas where ice might build up

Frozen horn cover: Use of a sock-like cover to avoid snow entering the horns

Snow deflector: Use of deflector under the bogie or next to the doors

Hot-air de-icing “skirt”: Covering the rolling stock with a skirt to keep the heat inside
Propylene glycol de-icing: Use of propylene glycol for de-icing or anti-icing

- Do you think the efficiency of the previous technologies justify the investment?

### Rolling stock

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Propylene glycol de-icing</td>
</tr>
<tr>
<td>Low</td>
<td>Hot air de-icing with skirts, Material coating</td>
</tr>
<tr>
<td></td>
<td>Heaters DC Bias, Electric pulse, De-icing boot</td>
</tr>
</tbody>
</table>

### Infrastructure

- In which way does your company cooperate with the rail administration (JBV)?
- Did the railway owner experienced winter problems in the past?
- What was the problem and in which way it affected the operation?
- What was the cause of the problem? Inadequate design, lack of equipment?
- How did you solve the problem both on short and long-term? Was it successful?
- Did any of the following technology was used to cope with winter problem or do you think it would help dealing with winter? For descriptions of the technologies, refer to document “Winter problems.pdf”

Snow and avalanche fences: Use of fence to reduce snowdrift or avalanche

SnowProtec: Brushes used to keep railroad switch heat and reduce snowdrift
Railroad switch cover: Use of plastic and wooden cover to retain railroad switch heat

Sprinkler system or slush-mixture pumping system

Viaducts: Increase the snow storage area

Larger cuttings: Increase the snow storage area

- Do you think the efficiency of the previous technologies justify the investment?

**Infrastructure**

<table>
<thead>
<tr>
<th>High Efficiency</th>
<th>Low Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Investment</strong></td>
<td>Rail Road switch design</td>
</tr>
<tr>
<td>Sprinklers and slush-mixture pumping system</td>
<td>Railroad switch heaters</td>
</tr>
<tr>
<td>Viaduct</td>
<td>Larger cuttings</td>
</tr>
</tbody>
</table>

- Fences and SnowProtect brushes

**Operations**

- Did your company experienced problem related to the management of winter? For example a lack of employees on a snowstorm or lack of equipment
- What is the winterisation program of the company? When is it applied?
- How do you cope with an upcoming winter storm? In which case is it considered normal to have delays?
- Do you transfer the customers to an alternative mean of transportation in case of shortage due to weather?
• Do you use a reduce service plan to decrease the use of railway switches? For example, setting the railway switches for the busiest routes before the snowstorm and switching it only when all the trains of this route have left.
• Do you use shorter trips to avoid chain reaction of delays as seen in the next picture (ADVD)?

Regular Operation

ADVD


VIII. APPENDIX 2 - LEXICON

**Active Suspension:** A recent development in train ride control, active suspension uses microprocessor control to detect changes in track formation or direction and then signal changes in the suspension configuration. In this way, sideways movements can be used to stiffen hydraulic resistance in dampers or induce hydraulic jacking movement to adjust body tilt.

**Adhesion Coefficient (m):** The ratio of the tangential and normal forces that exist between the wheel and the rail at standstill and during motion. The adhesion coefficient for rolling motion is usually referred to as \( m_R \). Generally taken as 0.3 to 0.4 for dry rail, but can be as low as 0.01 for icy and greasy rail.

**Axle:** The circular shaft connecting two wheels to form a 'wheel set'. The wheels are an interference fit to ensure the gauge is maintained. Wheels are removed by forcing them off after injecting oil under high pressure into the wheel hub through a specially designed aperture drilled in the hub.

**Ballast:** The material most commonly used to form the road bed of a railway track. It is laid on the base formation of the track with the track laid on top of it and provides a storm water drainage medium. It usually consists of granite, whinstone or furnace slag. Ash is sometimes used in yards but not where any sort of speed is required as the dust gets into the rolling stock equipment. A properly maintained railway will have regular tamping of ballast to ensure the track itself is maintained to provide an acceptable standard of ride. Other track forms include slab or non-ballasted track which does not require ballast.

**Bogie:** A 4- or 6-wheeled truck used in pairs under long-bodied railway vehicles. The bogie has a central pivot point which allows it to turn as the track curves and thus guide the vehicle into the curve. In the US it is always referred to as a truck. There are almost as many bogie designs as there are bogies. All-welded box-frame bogies with some
steering capability are currently the fashion in Europe. Good design is crucial to good riding, although track condition is also very important in giving a good ride.

**Catenary:** Originally the term used to denote an overhead power line support wire derived from the curve a suspended wire naturally assumes under the force of gravity. Now adopted to mean the whole overhead line system.

**Coefficient of Friction:** The factor used to determine the maximum tractive effort which can be applied by a locomotive under a given rail condition before slip occurs. It is denoted by the Greek letter μ and may vary between 0.1 and 0.4 in UK conditions.

**Conductor Rail:** An additional rail (or rails) provided on those electric railways where power is transmitted to trains from the track. Often referred to as the 'third rail' or 'current rail', it is normally at positive potential and is mounted on insulators to the outside of and slightly higher than the running rails. The return of the circuit is via the running rails. The current is collected by the train through 'shoes', attached to the bogies, which slide along or under the rail. Varieties of the system include top, side and bottom contact rails. Top contact rails are susceptible to ice and snow contamination in cold climates and present a certain risk to persons walking on the track. For this reason, bottom contact rails are preferred for modern systems.

**Crossover:** A track providing a connection between two parallel tracks using two sets of points. A scissors crossover provides two connections, one in each direction.

**Detection:** In railway signalling, the ability to determine that a track section or block is occupied by a train. Detection is usually by a track circuit or equivalent electrical loop. Also used to verify that a point or signal has operated correctly as part of the interlocking.

**DMU:** Diesel Multiple Unit - the generic term for a diesel powered train where a separate locomotive is not required because the traction system is contained under various cars in the train.
EMU: Electric Multiple Unit - the generic term for an electrically powered suburban or metro train where a separate locomotive is not required because the traction drive and control system is contained under various cars in the train.

Gangway: Flexible structure provided at vehicle ends where necessary to provide access from one vehicle to another. The gangway is divided between the two adjacent vehicles and is normally closed off when the vehicles are uncoupled.

Horn: Electrically or pneumatically operated warning device provided for a driver to sound at will. Replaces the traditional whistle.

Overlap: The safe braking distance beyond a signal provided in case the train fails to stop at the signal when it is showing a danger aspect.

Overrun: Distance allowed beyond a normal stopping point in case a train fails to stop in the correct position. The distance is dependent upon speed and braking capacity of the train.

Pantograph: Folding traction current collection device mounted on the roof of a vehicle on a railway employing an overhead supply system. Nowadays, pantographs are sophisticated aero-dynamically designed devices which can operate at high speeds without loss of contact and with built-in safety devices which reduce the risk of damage to wires in the event of a fault. A common problem is when a pantograph catches above the wire and pulls it down for considerable distances before it is noticed by the crew and the train stopped. Modern pantographs are fitted with automatic detection and lowering devices. The horns (curved edges) of the pantograph are equipped with frangible pneumatic sensors which, if broken by a wire support, cause the detector system to lower the pantograph.

Primary Suspension: On a railway bogie, the flexible interface between the vehicle axle and the bogie frame. It can consist of steel leaf or coils springs or rubber blocks.
**Slab Track:** A form of railway track comprising a concrete base to which the chairs carrying the rails are secured. It eliminates the need for individual "sleepers".

**Sleepers:** In the US known as "ties", short for "crossties". The transverse members of track work made of wood, concrete or sometimes steel, which are used to secure the rails at the correct gauge. Cast steel chairs fixed to the sleepers hold the rails in place by means of clips or keys.

**Track Gauge:** The distance between the inner faces of the rail heads of a railway track, commonly referred to as "the gauge".

**UIC:** Union Internationale de Chemin de Fer - International Union of Railways - the French dominated European railway regulating body which sets engineering and operating standards for railways.

**Under frame:** Railway vehicle base which forms the support for the body structure or is an integral part of a body shell.

**Wheel set:** A fixed formation of an axle with two wheels set at the correct gauge for the track. The wheels are pressed onto the axle and rotate with it as a unit. It is mounted into the bogie (or vehicle) frame with axle boxes.