Impact of climate on railway operation - a Swedish case study

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It is well known that the railway network and infrastructure is sensitive to disturbances caused by climate changes. Hot days can cause rail buckling, thunder storm causes signalling failures, cold can lead to rail breakage, snow and wind can cause disruption of services and train delays. In short climate has considerable impact on the reliability and availability of railway system. The result from the study shows that occurrences and types of failures can be systematically linked and related to prevalent weather conditions, geographical location (near water, up in the mountain) of infrastructures, etc.

Index Terms: Weather related failures, railway infrastructure maintenance,

1. Introduction:

It is well known that the railway network and infrastructure is sensitive to disturbances caused by climate changes. Hot days can cause rail buckling, thunder storm causes signalling failures, cold weather can lead to rail breakage, snow and wind can cause disruption of services and train delays. In short climate has considerable impact on the reliability and availability of railway system.

This paper will discuss the failures that are mainly caused by variation in climatic condition characterised by temperature, wind and precipitation, etc. It presents a case study using weather statistics, asset information and failure data to study the effects of “extreme” climate on railway infrastructure reliability. The purpose is to identify and assess the impact of climate changes, suggest measures to deal with such situations, also suggestions for redesign to avoid future failures and unavailability caused by climate changes. Parts of the result will be presented as well as methods of analyzing the data. ‘

2. Case study; Section Boden - Gällivare

The railway section Boden – Gällivare is 161 km long and represents one part of the Iron Ore Line between Luleå and Narvik, see Figure 1. The section is operated by passenger, freight and iron ore trains and the maximal axle load is 30 tonnes. Loaded iron ore trains are operated from Gällivare situated 400 m above see level to the harbour in Luleå, see Figure 1. Since the curvature consist of several narrow curves with radius less then 600 m, the maximal speed for passenger trains are restricted to 120 km/h. The annual traffic tonnage on the track is around 13.8 MGT and the section is crossing several types of geographical terrain, soil and weather conditions. The track structure consists of UIC60 rail, pandrol fastenings and concrete sleepers. There are a total of 17 meeting yards and a total of 36 switches and crossing (S&C) in main track; most of these are UIC60 1:15. The section is electrified and is operated from the train control center in Boden. Other assets are:

- 14 Interlocking model 59 based on relay technology
- ATC Automatic Train Control
- 247 Positioning systems
- 29 Wayside monitoring sytems, 32 of them are derailment detectors, 6 are hotbox detectors and one is a wheel flat detector.
- 1 Electrical supply subsystem in Murjek
- 11 Road crossings equipped with road barriers and signalling system
- 167 Insulated joints

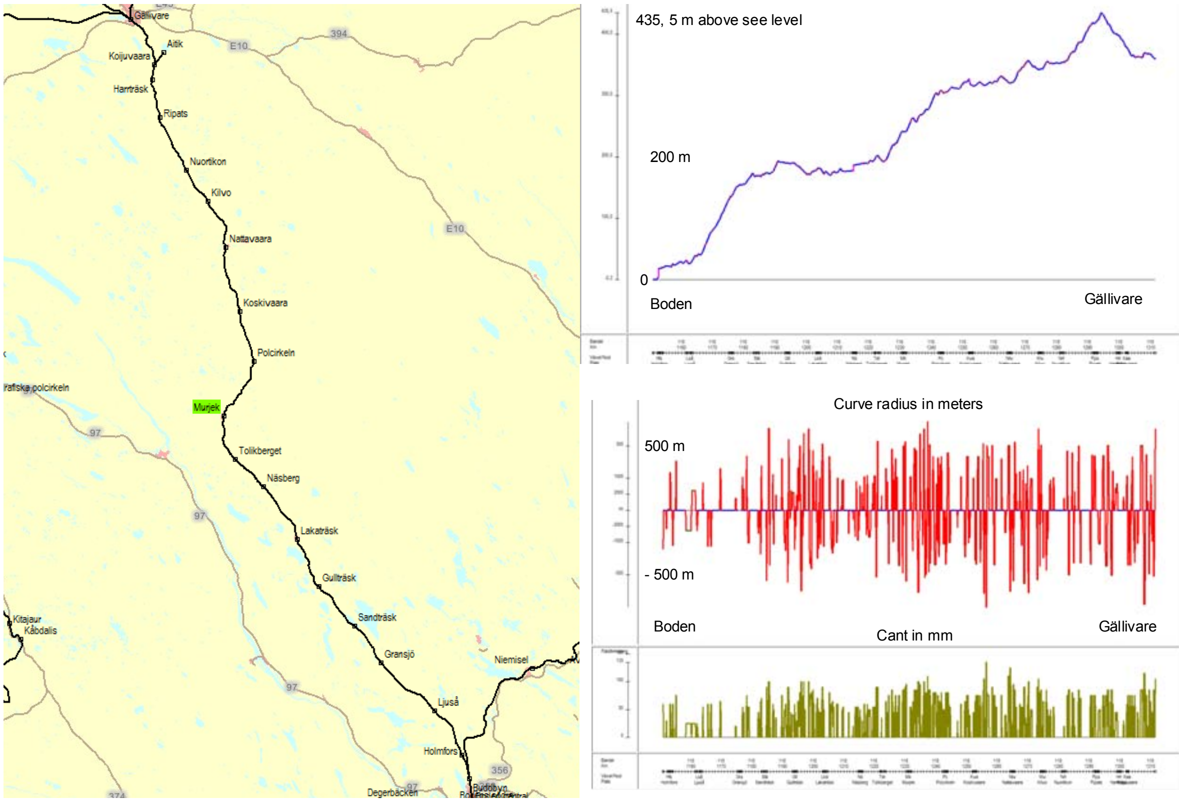

Figure 1: Section Boden – Gällivare, geographical extension, gradients and curves [1].

3. Methodology:

3.1. Data collection

Data has been collected from Trafikverkets failure system Ofelia [2], asset information from BIS (Asset Information system) [1] and Swedish Meteorological and Hydrological Institute (SMHI) has provided weather data from their weather stations for precipitation, temperature and wind in Lakaträsk, Nattavaara and Gällivare for the period 2006-01-01 - 2010-12-31.

Trafikverkets failure system Ofelia was introduced in late 1999 and includes data of all failures reported to the train control center. Every failure is given a unique number. Time, date, place for the failure is noted as well as the symptom and the real cause of the failure [2]

Detailed asset information is reported into BIS, but also some events e.g. tamping, grinding, geotechnical events. BIS describes how the track is located geographically, near by lakes and rivers, mountains and marshlands. It also describes if the track is situated on an embankment, in cuttings or in tunnels [1].

SMHIs weather data from Lakaträsk, Nattavaara and Gällivare are grouped into two excel sheets, of which one contains data on the amount of snow and rain/snow fall per day in mm and the other shows temperature, wind speed and direction every three hours.

3.2 Methodology

The case study is based on a number of experience based hypothesis, such as snow in combination with wind will cause S&C (switches and crossings) to malfunction, a lot of snow with/and with out wind will cause the road barriers at level crossings to fail, lightning may cause failures in the power supply etc. Five different analysis steps have been undertaken and an observant reader will notice that a sixth and seven step will be needed i.e. the impact of the asset age and how it is operated which though has been excluded due to lack of data.

The first step explores what kind of failures that are most common and were and on what time of the year they occur. Data has been collected from Ofelia.

The second step investigates if certain weather condition increase the failures, e.g. max/min temperature, max/min rain/snow, max/min wind speed and in combination with each other. The methodology used is;

1. SMHI data: Find days with a maximum value for precipitation, temperature and wind.
2. SMHI data: Note down other weather events that occurred the same day that may have a synergistic effect that makes the weather conditions deteriorate further.
3. Ofelia data: Have failures been reported the current date, and in case of; how many failures, on what assets, where and what caused the failure.

The third step is to investigate if there are failures reported into the failure system Ofelia coded as “weather related”, and on what assets they are reporter.

The fourth step investigates where most failures occurres and in what kind of geographical environment the assets are located e.g. uphill and if their location contributes to the failures. Data has been collected from BIS.

In the fifth step the results of step 1 to 4 is analysed and aggregated to a level that shows most failed assets, most failed root causes due to weather conditions and geographical conditions.

4. Results

Step 1: A total of 3043 failures have been reported into Ofelia during the period 2006 to 2010. Most failed assets/events are S&C with 17 % of all failures, animals in track 17 %, track 11%, “the failure disappeared” 9 %, train position system 6 %, signals 5 % and way side monitoring equipment (5 %). The code “the failure disappeared” was introduced to capture those occasion when the train dispatcher tries to set a new train route but has to attempt it several times before it comes into position, which means that S&C causes almost 25 % of all failures. Today “the failure disappeared” is also used for other failures that have occurred, but where no root causes has been determined.

How the failures are distributed per month is shown in Figure 2, which shows the accumulated failures per month for the period 2006 to 2010. There are fewer failures during August to October when the average temperature is 4 °C.

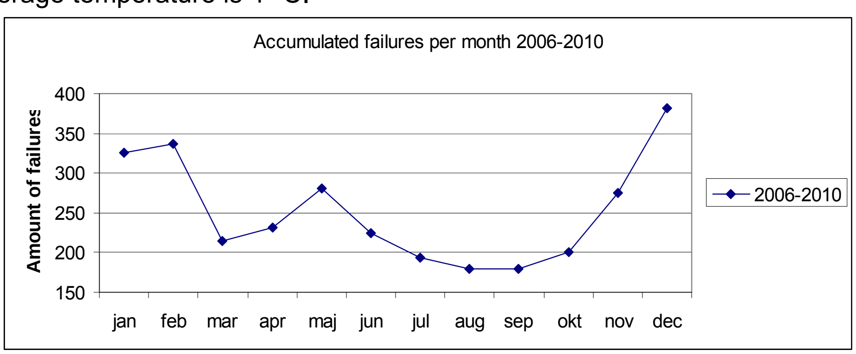

Figure 2: Accumulated failures per month 2006-2010.

Step 2: According to SMHIs statistics, the following are the most extreme weather conditions recorded during the period 2006-2010; coldest temperature - 37,4 °C and warmest + 31,7 °C, maximum precipitation,43 mm rain and maximum wind speed 11 m/s. Table 1 shows the result from the methodology described under step 2.

During the period 2006-2010, the wind has blown from north 45 % of the time, from west 16 %, east 11 % and south 28 % (wind direction measured at 12 midday, direction north 0 ±10, east 90±10, south 180 ±10 and east 270 ±10).

Table 1 "Extreme" weather conditions and failures. Grey shaded = Prioritised extreme value.

Date	Temp °C	Wind m/s	Rain/snow mm	Failures reported in Ofelia, Amount: were and what
20060708	25,1	4	43	3: 2 signalling boxes Nattavaara – Kilvo and Koskivaara - Kilvo. 1 in Murjek substation. Failures were caused by thunder.
20070712	13,9	2	41,6	1: failure in substation Murjek, short circuit
20100722	21	5	37,7	7: 5 in signalling boxes Kilvo (2), Murjek (2), and Holmfors - Boden caused by thunder. 1: support power line between Nuortikon-Kilvo. 1: animal in track Ljuså-Gransjö
20070917	2,2	4	36,2	No failures
20080719	13,9	4	35,1	No failures
20100127	-4,6	3	15,7	5; 2 S&C, snow and ice in Lakaträsk to Ripats and weak material Lakaträsk 2: road crossing Polcirkeln and Näsberg, 1: S&C Lakaträsk, position system caused by snow and ice
20081212	-11,5	0	29,7	5: 2 Animals in track, 1 S&C Ljuså heating system not working. 1 Ljuså Signalling station n and 1 S&C Ripats- cant be manoeuvred
20080813	13,9	2	34,9	No failures
20070206	-37,4	0	0,4	4; 3 S&C Holmfors, Kilvo and Lakaträsk 1 track circuit between Nuortikon and Ripats
20100107	-36,2	0		10: 6 S&C Holmfors, (2) Lakaträsk, Ljuså, Murjek, Tolikberget, 1 signalling station Ljuså, 1 deformed catenary Murjek - Polcirkeln. 1 Ljuså signals, cause snow and ice, un normal temperature 2: incident accidents in Holmfors
20100224	-36,8	2	0	2: S&C in Lakaträsk and Tolikberget, snow and ice
20100129	-36,6	2	2,6	4: 2 S&C Nattavaara, Lakaträsk, 1 way side monitoring equipment. 1 position system
20101229	- 35,5	0	0	9; 1 signal failure in Lakaträsk. 7 position system between Lakaträsk and Polcirkeln and (1) Harrträsk - Ripats caused by failure disappeared. 1 catenary failure Polcirkeln.
20060613	31,7	4	1	6: 5 S&C in Harrträsk (2), Lakaträsk, Gullträsk, Nattavaara, 1 catenary Murjek – Näsberg. Cause temperature shift
20060612	27,1	3	0	2: S/C Ljuså and Lakaträsk caused by high temperature
20090419	-1,9	11	0,1	No failures
20071220	1,1	11	0,7	3 failures: 1 Nuortikon - Kilvo signals out of order, 1; Tolikberg - Näsberg Automatic train control out of function, 1 Signal station at Tolikberg fails
20070427	-4,7	10	0,3	2: 1 inspection track after wheel flat, Riptas – Nuortikon, 1 Animal in track Holmfors
20081231	-7,1	10	0,3	3; 1 signalling station Sandträsk - Gransjö (2) and Lakaträsk. 1 S&C Kilvo
20090419	0,3	10	0,1	No failures
20060412	2,5	10	0	No failures
20060224	3,3	10	0	No failures
20070402	1,7	10	0	4: 2 S&C Holmfors, 1 Power Substation Murjek. 1 signalling station Murjek
20071219	2,6	10	0	3, 1 Animal in track Ripats-Nuortikon, 1 signal station Nattavaara. 1 positioning system Sandträsk-Gullträsk
20081229	3,5	10	0	No failures

Step 3: The weather related codes used in the system Ofelia are "snow and ice", "track buckle", "wind/storm" and "thunder lightning". Only one possible track buckle has been reported during the period (the air temperature that day was 24,3 °C) and just eight reports on failure caused by wind/storm or trees falling in track. The wind speed were 4 and 5 m/s. The code "snow and ice"

was mainly reported as root cause to failures in S&C, see Figure 3, 34 % of all failures in S&C were caused by snow and ice. The period 2006-2009 can be seen as "normal winters" while winter 2010 had a very long period (from December until middle of March) with temperature below 0°C and snow, see dotted line in Figure 3: The average number of failures during 2006-2009 was 5 failures per yard. This increased to 11 failures per yard during 2010. Ljuså, Lakaträsk and Tolikberget had most failures in S&C caused by snow and ice.

Other assets that failed due to snow and ice are road crossings. During the period 24 failures caused by snow and ice and the road crossings at Polcirkeln and Sandträsk were especially affected.

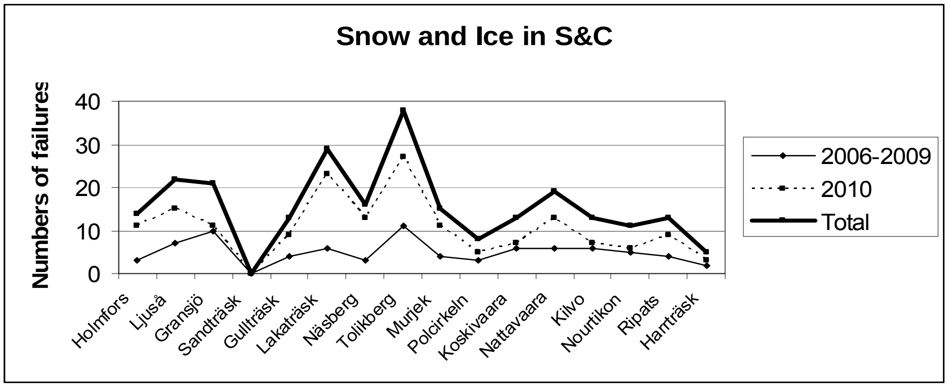

Figure 3. Snow and ice in S&C.

Step 4: Geographical conditions; most failures occurs at Holmfors-Ljuså, Lakaträsk, Näsberg-Tolikberg, Murjek and Nattavaara. See Figure 4.

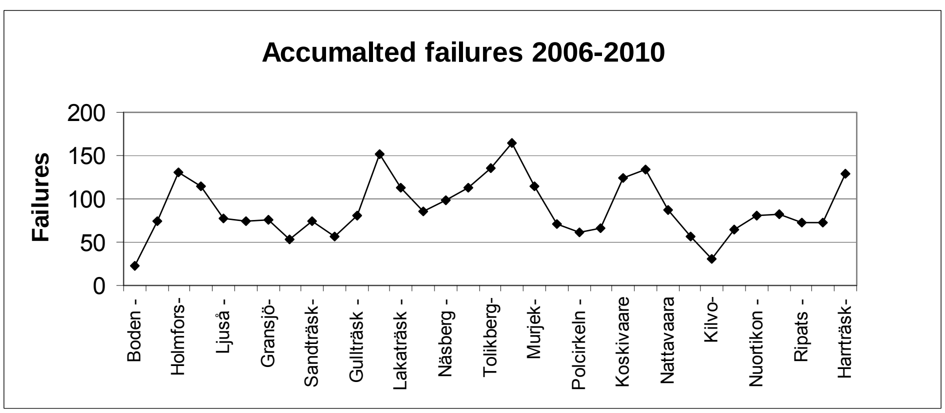

Figure 4. Accumulated failures

Figure 5 shows in what kind of geographical condition most failures occurs. Geographical conditions have been group in "up hill", "down hill", near "lake/river", near "mountain", "marshland" and "geotechnical events". There are a total of 56 geotechnical locations with an average length of 100 m that have had problems with frost extension, erosion and subsidence [1]. If a geographical condition has occurred on a section/yard, it has been given the value = 1. In order to show the density of curves, the number of curves with a radius less than 600 m have been summarized per section and multiplied with 0,25 in order to scale the geographical event "curves" in parity with other geographical conditions. A similar procedure as has been conducted to compare steep gradients towards small ones. Section/yards with high density of geographical conditions are Lakaträsk, Murjek-Polcirkeln and Koskivaara – Nattavaara.

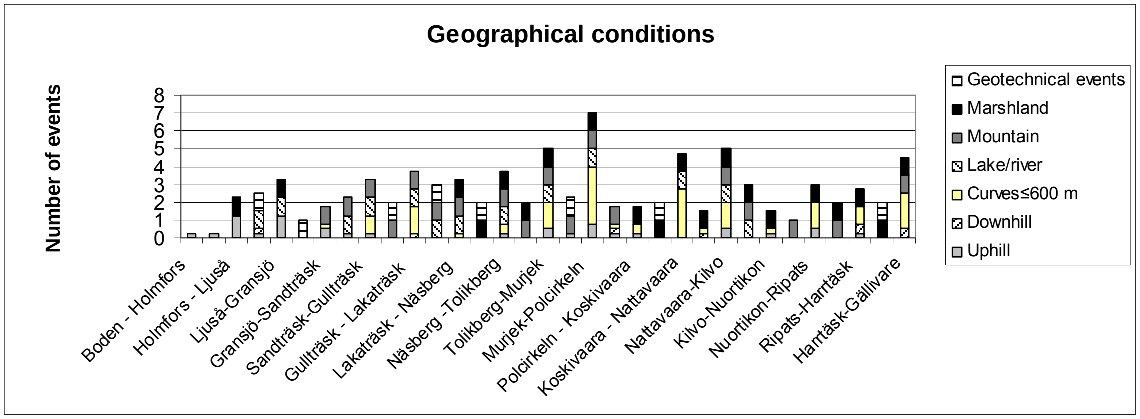

Figure 5. Geographical conditions

Step 5; Analysis of results and aggregation; the results from step one shows that the most sensitive asset is S&C and that the most critical period for the assets to fail are November to March and April to May when the frozen substructure is warming up, causing movements in the track infrastructure.

The results from the weather condition has been group in high air temperature (warm), cold temperature (cold), snow and ice, rain and wind and related towards failures in assets, see table 2. The result indicates that cold temperature has the highest impact on the failure rate and especially vulnerably assets are S&C. These failures occur most frequently between Lakaträsk and Murjek, and at Ljuså and Kilvo.

Table 2 Weather conditions that causes failure on railway assets

Assets/Weather condition	Total	Warm	Cold	Snow and ice	Rain	Wind
Signalling box	14		1	1	7	5
Power substation	3				2	1
Power support wire	1				1	
S&C	26	7	11	5		3
Road crossing	2			2		
Positioning	9		8			1
Track Circuit	1		1			
Catenary	3	1	2			
Signals	2		2			
Wheel flat	1					1
Way side monitoring equipment	1		1			
ATC	1					1
Total		8	26	8	10	12

In Figure 6 the numbers of failures caused by extreme weather conditions (according to step 2) has been related with weather related failures reported into Ofelia.(see step 3). Figure 6 shows that there is a correlation between “extreme weather conditions” and snow and ice. It also shows that most affected section/yard is Lakaträsk, Ljuså, Murjek, Tolikberg –Murjek.

Figure 7 shows sections/yard sensitivity for weather related failures on an aggregated level, so to say that sections and yards causing less than 5 % of their failure in their own category has been excluded.

Sections with increased vulnerable towards failures (not just weather related) are Näsberg to Murjek, see black bar in Figure 7. Particularly vulnerable sections of extreme weather conditions are e.g. Gullträsk to Murjek.

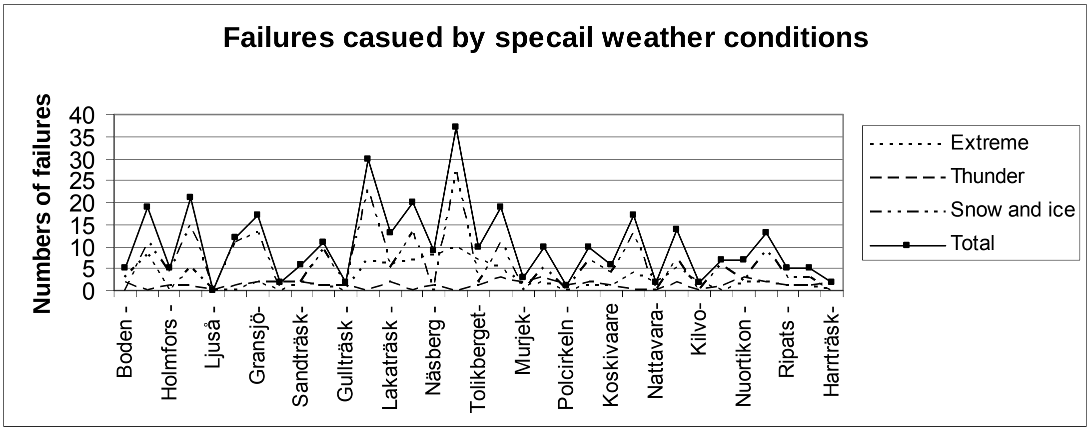

Figure 6. Failures cause by special weather conditions

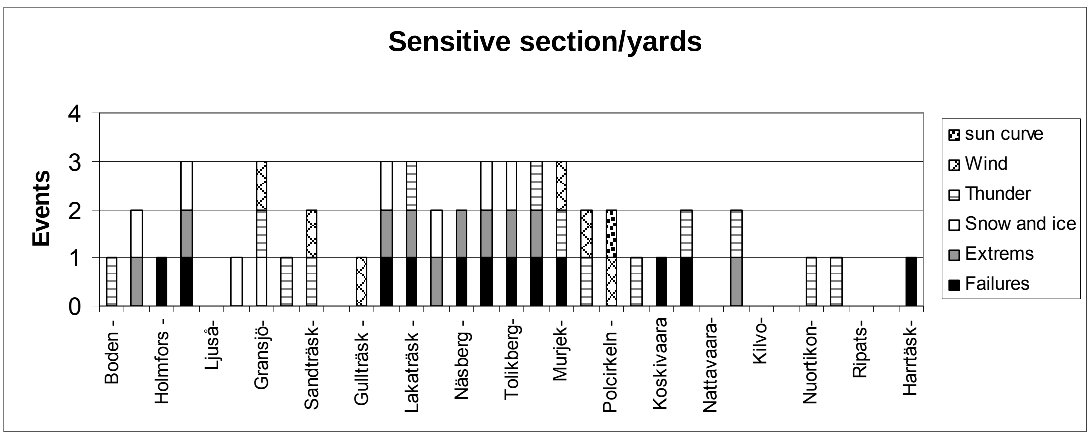

Figure 7. Sensitive sections/yards

Finally grouping geographical conditions towards weather related conditions and failures is showed in Table 3.The geographical conditions “near water, mountain and marshland” could not be correlated based on the existing definitions and a more specific interpretation is required e.g. concerning what to be regarded as near by a mountain.

Table 3. Geographical conditions related to Weather conditions

Geographical Conditions/Weather condition	Failures	“Extreme weather conditions	Snow and ice	Thunder and lightning	Wind	Sun curve
Uphill	yes	yes	yes	yes	yes	yes
Downhill	yes					
No inclination	yes			yes		
Valley				yes		
Curves < 600 m	yes					yes
yards	yes	yes	yes			
Geotechnical events						
Marshlands	?	?	?	?	?	?
Mountain	?	?	?	?	?	?
Near water (lake/river)	?	?	?	?	?	?

Table 3 indicates e.g. that the condition “uphill” triggers all kind of failures. Uphill is vulnerable for thunder lightning and snow and ice.

5. Discussion and conclusion:

The result from the analysis must be regarded as a first hypothetical approach, since it based on several assumptions that require more detailed investigation and definition, such as curves with radius less than 600 m are supposed to cause more failures as well as the affect of the geographical conditions “mountain”, “near lake/river” and marshlands need more specific definitions. Furthermore it is important to include the age of the asset and how it is operated. It is also possible to get information of train delays caused by infrastructure failures if one might be interested of describing the unavailable effects of a train system.

However some hypothesis has been partly confirmed such as S&C and road crossing will fail due to snow and ice. The result from the case study also indicates that weather related failures can be linked towards the assets geographical locations, see Lakaträsk. One interesting observations is that the optimal weather conditions for railway assets reliability, occurs during August to October in spite of rain and heavy winds.

By predicting the probability for a failure to occur (see Figure 2) it also would be possible to allocate the emergency organisation at right place in right time. An Improvement area is to investigate and find the root causes to the increases in failure in November and May and suggest solutions.

In order to get right results from a reliability analysis it is important to consider failure statistics, weather statistics and geographical conditions. This should be regarded during the investment phase in order to decrease the life cycling cost during the operation and maintenance phase, e.g. 2 new yards was installed during the period. Tolikberg between Näsberg and Murjek in 2007 and Kojuvaraara between Harrträsk and Gällivare, both of them increase the number of failures. The root cause might bee their geographical location.

Measures to deal with weather related situations might be geographical conditions , weather related conditions, number of failures cause by whether related events, number of weather related failures located to special geographical locations.

Finally bad weather affects the performance of railway infrastructure. By analysing and finding the root causes better preparedness can be obtained in the investment and operations and maintenance phase for the railway system and will decreas the total life cycling cost.

6. References

[1] Trafikverket Anläggningsinformation (2010) BIS Ban Informations System (Asset Information)

[2] Banverekt Banportalen (2010)OFELIA – 0 fel i anläggning (zero failures in the assets)