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Climate change and infrastructure performance: should we worry about?

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Abstract

Although it has been known for a while that climate-related factors account for the performance development of infrastructure, it remains difficult for infrastructure manager to estimate the effect of the anticipated climate change. The impact of climate factors differs very much between geographical locations and therefore a climate change assessment requires a more detailed analysis of the particular network. In this paper data about actual infrastructure performance of two railway tracks in the Netherlands are correlated with regional climate data in order to model future performance and apply appropriate interventions to cope with climate change effects. The analysis revealed an opposite climate change effect. In winter time the number of incidents will decrease whereas in the summer time the number of incidents will increase.

Keywords: climate change; maintenance; performance; railway infrastructure; weather effects

1. Introduction

Over the last decades climate change has been on the top of the political agenda and many organizations have undertaken various efforts to determine the effects of climate change on our daily and future life, including judgements about mitigation and adaptation costs. That also includes several endeavours to reveal the influence of climate change on infrastructure networks (e.g. Leviäkangas et al. 2011, Enei et al. 2010, Papanikolau et al. 2011, Koetse & Rietveld, 2009; Hughes et al. 2010; Dobney, 2010; Baker et al. 2010; Bles et al., 2010).

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Although it has been known for a while that climate-related factors account for the performance development of infrastructure, it remains difficult to estimate the effect of the anticipated climate change. Many studies are restricted to a more general and qualitative analysis of possible climate-induced effects on infrastructure performance which can be mainly traced back to the uncertain and global climate models underlying the analysis (Leviäkangas et al. 2011, Enei et al. 2010, Papanikolau et al. 2011, Bles et al., 2010). However, since climate factors differ very much between geographical locations, it can be expected that the climate change effects differ as well across regions. Therefore more detailed analysis of the particular network is required to be able to decide on necessity and appropriateness of intervention measures. In addition, for many infrastructure managers climate change appears as an uncertain future event which is hardly to translate into day-to-day decisions. National adaptation programs of EU Member States, the US, Canada, New Zealand and the 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC) provide only indicative measures and global fields of action. Thus there is a need for more studies addressing local climate conditions and infrastructure peculiarities (Enei et al. 2010), in order to assist infrastructure managers in answering the question whether they should worry about the performance of their infrastructure in the light of a changing climate.

This paper reports on the first results of a research project aiming at the improvement of the maintenance, rehabilitation and renovation decision making at public agencies by integrating three interlinked areas: climate change, infrastructure asset performance and policy development. The paper focuses on the number of incidents that can be expected for two railway tracks in the Netherlands under four different climate scenarios.

2. The nature of climate change in the Netherlands

Although there are many uncertainties concerning the degree of climate change in the world and its consequences on all natural and human systems, most scientists are convinced that continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century (IPCC, 2007).

According to the results of Dutch studies to date, climate change has not led to any serious problems in the Netherlands. However, the climate is changing and the main characteristics are the following:

- during the last century mean temperature has risen by about 0.7°C worldwide and in the Netherlands by about 1°C;
- the sea level along the Dutch coast has been subject to an autonomous rise of about 20 cm per century as a consequence of climate changes (melting of land ice and glaciers and expansion of seawater due to temperature rise) and land subsidence;
- the river discharges are changing: higher winter discharges and lower discharges in dry periods, with climate change playing a likely role in this;
- average annual precipitation in the Netherlands is increasing, and there is a tendency towards more days of rain and an increased frequency of extreme rainfall.

Over the next few decades climate will change more quickly:

- the average global temperature will almost certainly increase further (1–6°C in 100 years); this increase is also expected for the Netherlands; the frequency of dry and extremely warm summers, such as that of 2003, will increase; the probability of extremely cold winters will decrease. The chance of drought during the summer is expected to increase;
- an increase in the average precipitation and extreme rainfall is expected throughout the world, but the regional distribution is still highly uncertain; in the Netherlands there is likely more precipitation

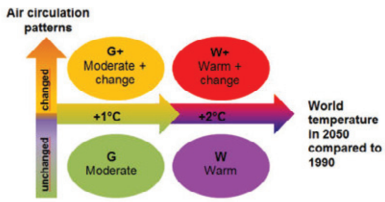
during the winter and summers will be drier; there will be an increasing probability of extreme rainfall with local floods;

- a further rise in temperature is highly likely to lead to a more rapid rise in sea level and greater dynamics in river discharges (more than now). Towards the end of this century, the sea level will have risen by 20 –110 cm. This wide range is indicative of the degree of uncertainty that still exists. Recent research points to a rise that lies more towards the upper limit of this range or even possibly above this. The chances of floods will likely increase further, due to an expected increase in the number of episodes of extreme rain. (Bresser et al., 2005)

Predictions on climate change in the Netherlands require insights into regional climate expectations as well as global trends. In 2006 the KNMI (Royal Netherlands Meteorological Institute) has published four different climate scenarios into which our climate may develop. These four scenarios differ in the degree of global temperature rise and the degree of change in atmospheric circulation patterns in our region. By making a simple assumption the influence of future climate on the railway for winter conditions and heat can be qualitatively assessed (Hurk et al., 2006). In 2009 the KNMI evaluated the KNMI '06 scenarios with the state of knowledge at that time. The conclusion was that there is no reason to change the KNMI'06 scenarios. Important changes since the introduction of the KNMI '06 scenarios include: the observed rapid warming of the Netherlands and Western Europe, the observed rapid decrease of large ice sheets on West-Antarctica and Greenland, and new research on precipitation patterns on the local and regional scale. The assessment was that the changes fall largely within the four KNMI'06 scenarios (KNMI 2009).

Table 1. Values for the steering parameters used to identify the four KNMI'06 climate scenarios for 2050 relative to 1990

Scenario	Global temperature increase in 2050	Change of atmospheric circulation
G	+1°C	Weak
G+	+1°C	Strong
W	+2°C	Weak
W+	+2°C	strong



3. The impact of climate change and weather on railway performance

Climate change effects, such as extreme weather conditions, on the operability of different transport modes and infrastructure performance are very different and can't be uniquely defined. Moreover the impact of climate factors differs very much between geographical locations and the level of the infrastructure development. A comparative study of Chinowsky et al. (2011) on the impact of predicted temperature and precipitation changes on road infrastructure in developing and developed countries illustrates that the pressure for developing countries to transfer a significant amount of annual expenditure to offset the effects of climate changes on road infrastructure will be greater than for developed countries.

Duinmeijer and Bouwknegt (2004) have done research on rail infrastructure failures due to adverse weather conditions in the Netherlands in year 2003. It appears that approximately 5-10 % of all failures are weather related. Most of the weather-related failures are caused by high temperatures, icing, storm and lightning. (Koetse and Rietveld, 2007)

The study of Dobney et al. (2009) shows that increased incidents of rail buckles on the UK railway network are associated with extreme high temperatures. They conclude that an increased frequency of high temperature (greater than 25°C) occurrence will increase track buckling and the associated costs of heat-related delays, if the track is maintained to the current standard. It has been also shown that present-day adverse weather conditions cause 20% of all unplanned delays on the UK railway network (Thornes and Davis, 2002). Table 2 gives an overview of the potential impacts of climate change on railway assets and railway performance.

The main goal of climate change impact assessment is to determine the relationships between the intensity of a given meteorological parameter and infrastructure performance parameters (e.g. observed disruption and accident rates). This also involves the identification of key thresholds where problems occur.

To fully understand the impact of climate change it is also very important to think about the future transport network, as how it will look like in 50 years' time. The range of climate change impacts primarily depends on the vulnerability of the network which has been changing during last 50 years. It is expected that with an increase in population, traffic density and vehicle development the network becomes more and more vulnerable (Jaroszewski et al. 2010).

Table 2. Relationship between climate effects and railway infrastructure

Climate Factor	**Expected Climate Change**	**Impact on Railway Assets**	**Impact on Railway Performance**
Temperature	High temperatures and heat waves Sudden temperature changes Intense sunlight	Signal failures Track buckling Slope fires Bridge deformations Overheating of tunnels	Decrease of safety
Precipitation	Intense rainfall Extended rain periods Drought	Damage to embankments Failure of drainage systems Flooding in tunnels and over bridges Scour at bridges Earthworks failures Faster plant growths, new plants	Decrease of availability
Wind	Higher wind forces Coastal storms and sea level raise	Damage to installations, catenary Restrictions / disruption of train operation (dewiring) Damage to embankments and earthworks Deterioration of structures – bridges and tunnels (corrosion, wind forces)	Increase of maintenance costs
Lightning strikes and thunderstorms	Increased number of thunderstorms	Damage to catenary and signaling	

4. Case study: Randstad railway network

4.1. Project plan

Climate has a strong effect on the performance of railway networks and it is expected that this influence will be even stronger with the anticipated climate change. However, the impact of climate factors (e.g. temperature, snow, rain, wind) on railway performance differs between geographical locations. It requires a detailed analysis of the particular network to be able to decide on the most cost-effective intervention measures. The research project "Sustainable Maintenance Policy for Infrastructure Networks" focuses on the railway network in the Randstad, the most populated region of the Netherlands and has the following objectives:

- determining the effect of local climate conditions on the vulnerability and deterioration of the railway network in the Randstad,
- assessing the criticality of increased performance failures of assets, groups of assets and local parts in the Randstad railway network due to climate change,
- developing cost-effective intervention measures to anticipate performance failures due to climate change.

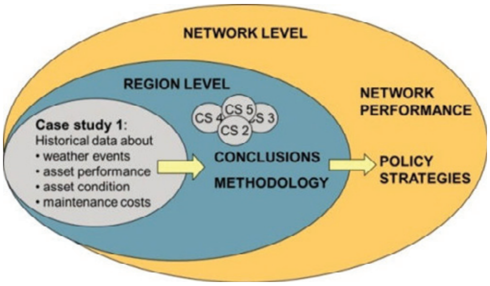


Fig. 1. Project methodology for the analysis of climate change influence on maintenance policy strategies

In order to increase the practical relevance of the research, the project tasks are developed in close cooperation with ProRail, the Dutch railway network operator. The project development is given in Figure 1.

Within the first phase of the project, two railway tracks were selected for investigation based on one or more of the following criteria:

- the track showed performance failures due to extreme weather conditions in the past
- the track required a high level of maintenance in the past
- the track is critical for the network performance
- climate data are systematically collected for the track.

The selected tracks include the track between Utrecht and Amsterdam (45 km) and the track between Rotterdam – The Hague – Utrecht (55 km). For both tracks data about availability in terms of delays and disruptions of train operation (duration), technical problems with signalling, catenary, drainage systems, structures, etc., and weather data from the closest measurement station have been collected. The period for which the data are collected depends on the availability of the data, and in this case was at first for 2008 to 2010, and partially extended to 2000. Based on the collected data the correlation between railway performance and climate data for the sections is established in order to predict the impact of climate change on railway performance. It is investigated to which extend the performance of the particular section will be affected by climate change in the future. In The results of the analysis will be used to identify risks/ vulnerabilities of the railway section. The risks will be classified and prioritised, in order to develop scenarios for the effect of changed weather conditions on railway infrastructure performance. The risks will be quantified and the costs of an intervention strategy without adaption to climate change will be determined. Different interventions strategies for the adaption of the railway section to climate change will be developed and their costs will be compared to the non-adaption strategy. This paper only focuses on the correlation of climate data with railway performance.

4.2. Analysis of data

For the selected tracks various datasets have been analysed for the period 2000-2010. The weather events are categorized in lightning, slippery rails (due to fallen leaves), heat, rain, storm and winter conditions. A first analysis of the datasets showed that the most weather-related incidents occurred during winter, but also during summer when warm temperatures are involved (Figure 2). The analysis provided below is therefore limited to winter and summer related incidents. The data on the weather-related incidents were combined with weather data for the period 2000-2010 which were obtained from the database of the KNMI (Royal Dutch Meteorological Institute).

Climate change scenario data used in this study are also taken from KNMI (2006). Time series of temperature are generated by transforming a time series of temperature using a program which is provided by KNMI on their website (http://climexp.knmi.nl/Scenarios_monthly/). This transformation can be executed for the average daily temperature, daily minimum and daily maximum temperature.

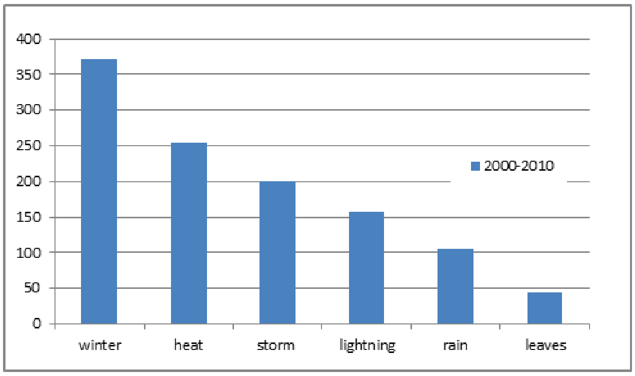


Fig. 2. Number of incidents caused by weather effects in the period 2000-2010 on 2 tracks (Utrecht-Amsterdam and Rotterdam-The Hague-Utrecht)

4.2.1. Winter conditions

From the dataset for the period 2000-2007 the number of incidents (any type of infrastructure failure) and for the period 2008-2010 the number of incidents and delay minutes were analysed, where one location appeared to be most problematic, ProRail geocode 80 in the length of 17 km in the Amsterdam county. In Fig. 3 relation between incidents and winter temperatures is given, and in Fig. 4 relation between incidents and snowfall appearance is presented.

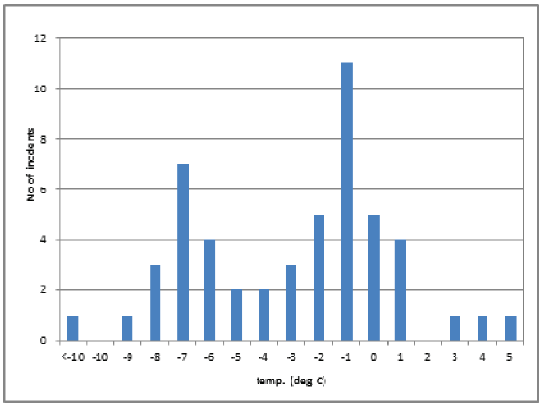


Fig. 3. Number of incidents for Geocode 80 (17 km length) for the period 2000-2010.

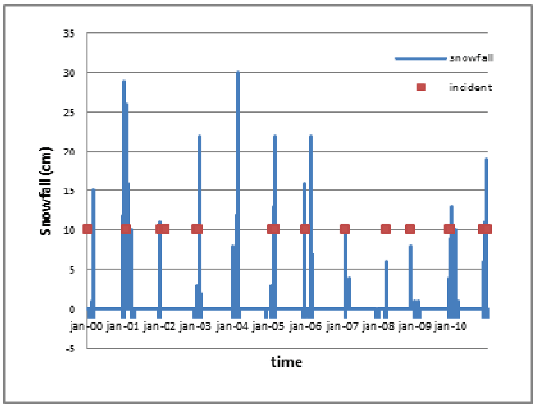


Fig. 4. Appearance of incidents related to the amount of snowfall (mm).

Weather data were collected from the meteorological station at Schiphol, closest to the selected track section. From the Fig. 3 it can be seen that there are two peaks with the highest number of incidents. At a temperature of -7°C the heating system of switches failed and at -1°C track and switches were blocked by snow. In Fig. 4 the data about snowfall are correlated to the incident appearance at the selected location. It is important to note that the majority of the incidents usually happened at the beginning of winter, or when the first snow fell.

In order to investigate how future number of incidents will change under the four KNMI climate scenarios, a simple theoretical relationship between the climate at Schiphol (DJF 2000-2010) and baseline incidents (DJF 2000-2010) was used based on Andersson and Chapman (2011):

Number of incident at Temp x / Number of day per winter at daily minimum Temp x (1)

Under future climate the number of incidents will decrease in wintertime (Figure 6). This is the direct result of the increase of temperature in wintertime as can be seen from Figure 5. In the W+ scenario the number of incidents is even half of the incidents observed during 2000-2011. It is noteworthy that this analysis is only based on temperature and not on snowfall. However, the amount of snowfall is about to decrease in the 21st century as a result of climate change with atmospheric conditions more suitable for rainfall.

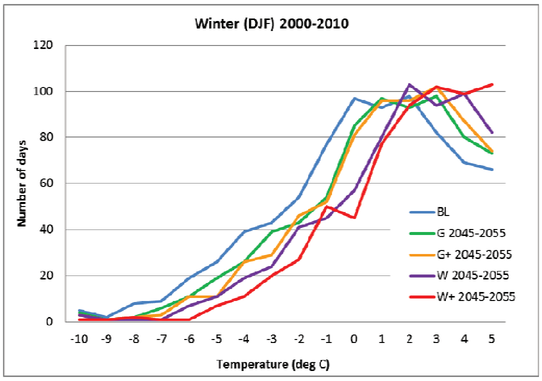


Fig. 5. Frequency distribution of temperature for baseline and the KNMI climate scnearios for Cabauw

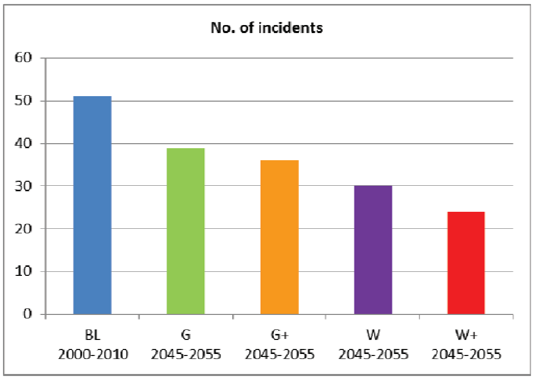


Fig. 6. Projected number of incidents for period 2045-2055 based on KNMI climate scenarios. The baseline is also shown based on 2000-2011

4.2.2. Summer conditions

The same analysis as above is presented for conditions where the railway experienced problems because of heat. The problems seem to be largest at the track between Utrecht and Rotterdam/The Hague and therefore the meteorological station of Cabauw was selected as closest for the comparison of historical data about weather and railway performance. The number of incidents for temperature intervals of 5 degrees were plotted in Figure 7. Most incidents occur at the 25-29 °C interval, although the incidents above 30 °C are quite important as well. The instances that the maximum daily temperature is higher than 30 °C are not as frequent as temperatures between 25 and 29 °C.

Figure 8 shows the Probability Density Functions (PDF's) for maximum temperature for the baseline situation (BL) and the four climate scenarios in an 11-year period from 2045 to 2055. It is clear from this graph that the temperature is about to rise in all four scenarios. This will have a significant effect on the number of incidents as well. In the worst case they may increase from 50 to just over 90 per 11 year period.

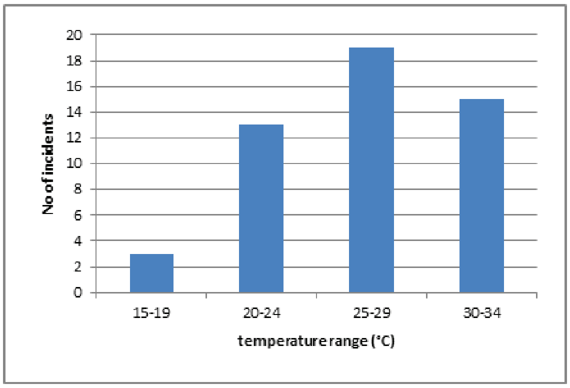
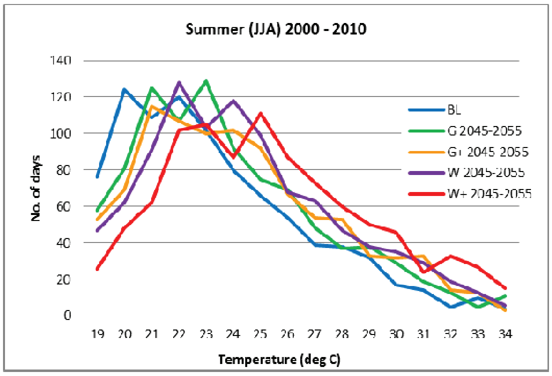


Fig. 7. Number of incidents as a function of temperature (observed at Cabauw) for 2000-2010



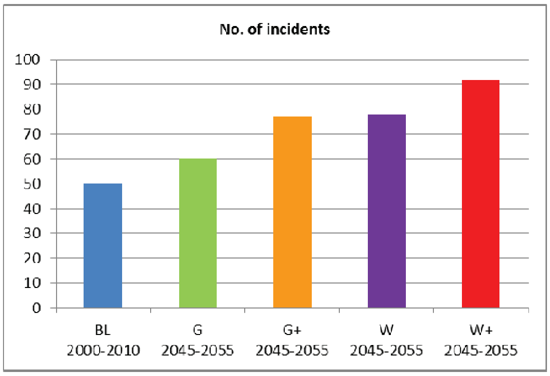


Fig. 8. Frequency distribution of temperature for baseline and the KNMI climate scnearios for Cabauw

Fig. 9. Projected number of incidents for period 2045-2055 based on KNMI climate scenarios. The baseline is also shown based on 2000-2011

5. Conclusion

Although it has been known for a while that climate-related factors account for the performance development of infrastructure, it remains difficult for infrastructure managers to estimate the effect of the anticipated climate change on infrastructure and the consequences for their daily decision-making. In other words, themain question is if infrastructure managers should worry about climate change. Since weather conditions differ very much between geographical locations, it can be expected that a change of these conditions will have locally different effects as well and therefore a detailed analysis of the particular network is required. In this paper data about the actual infrastructure performance of two railway tracks in the Netherlands are correlated with regional climate data in order to model future performance.

The analyses of total number of incidents related to weather effects gave the indication that the most critical weather events are high temperatures, snowfall and low temperatures. If the number of incidents are projected for four KNMI climate scenarios to predict future incident numbers, the temperature is about to rise for the period 2045 to 2055. For the two railway tracks under investigation that means an opposite effect on the expected number of incidents. In wintertime the number of incidents will decrease with an increase in winter temperature and probable decrease in snowfall. It can be concluded that since freezing temperatures will be experienced less in the future, winter maintenance will be less important. However, the analysis has also indicated that most problems occurred during first snowfall in the season. That suggests that the effect of low temperature and amount of snowfall is moderated by the preparedness of the agency. In summertime in the incidents may increase from 50 to just over 90 per 11 year period. Higher temperatures due to climate change seem to have a significant impact on the rail network. A closer look at the failure mechanisms will help the infrastructure manager to decide on cost-effective interventions to increase the climate robustness of the railway network.

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