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Adaptation to climate change in the transport sector

Seppo Saarelainen

FINADAPT Working Paper 8

FINNISH ENVIRONMENT INSTITUTE

ADAPTATION TO CLIMATE CHANGE IN THE TRANSPORT SECTOR

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FINADAPT WORKING PAPER 8

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Preface

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"[1]. The IPCC lists two reasons why adaptation is important in the climate change issue. First, an understanding of expected adaptation is fundamental in evaluating the costs or risks of climate change. Second, adaptation is a key response option or strategy, along with mitigation. Even with reductions in greenhouse gas emissions, some climate change is regarded as inevitable, and it will be necessary to develop planned adaptation strategies to deal with the associated risks as a complement to mitigation actions.

In Finland, there has been substantial progress during the past decade in investigating the potential impacts of climate change on natural and human systems. In contrast, there has been much less attention paid to adaptation. This was recognised by the Finnish Parliament as early as 2001, when it recommended that a separate programme for adaptation to climate change be initiated. As a result, a task force co-ordinated by the Ministry of Agriculture and Forestry completed Finland's first National Strategy for Adaptation to Climate Change in 2005.[2]

At about the same time as the Strategy document was being drafted, a research consortium named FINADAPT also began its work. The goal of the consortium, involving 11 partner institutions co-ordinated by the Finnish Environment Institute, was to undertake an in-depth study of the capacity of the Finnish environment and society to adapt to the potential impacts of climate change. FINADAPT was funded for the period 2004-2005 as part of the Finnish Environmental Cluster Research Programme, co-ordinated by the Ministry of the Environment. It comprised 14 work packages (WP) covering: 1) co-ordination, 2) climate data and scenarios, 3) biodiversity, 4) forests, 5) agriculture, 6) water resources, 7) human health, 8) transport, 9) the built environment, 10) energy infrastructure, 11) tourism and recreation, 12) economic assessment, 13) urban planning, and 14) a stakeholder questionnaire. The primary objective of FINADAPT was to produce a scoping report based on literature reviews, interactions with stakeholders, seminars, and targeted research.

This report, from work package 8, considers how climate change could affect the transport system in Finland. It takes an engineering perspective to climate change adaptation, focusing on the implications of changes in frequency and intensity of extreme weather events for the design and construction of transport infrastructure. The report highlights the probable need for modifications in design criteria, in building regulations and in service maintenance to minimise transport disruption under a changing climate in Finland.

Timothy Carter, Consortium Leader
Helsinki, December 2005

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[1] IPCC, 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds)]. Cambridge University Press, Cambridge and New York, p. 982.
[2] MMM, 2005. *Ilmastomuutoksen kansallinen sopeutumisstrategia* (Finland's National Strategy for Adaptation to Climate Change) [Marttila, V., Granholm, H., Laanikari, J., Yrjölä, T., Aalto, A., Heikinheimo, P., Honkatukia, J., Järvinen, H., Liski, J., Merivirta, R. and Paunio, M. (eds)], Ministry of Agriculture and Forestry, Helsinki (available in Finnish, 276 pp., Swedish 212 pp. and English, 280 pp.) http://www.mmm.fi/sopeutumisstrategia/

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ADAPTATION TO CLIMATE CHANGE IN THE TRANSPORT SECTOR

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Executive Summary

Introduction. The vulnerability of Finnish transport networks to climate change impacts depends on the conditions and response level of the transport systems. Most foreseeable impacts are taken into account in the current practice of design and construction, but design criteria may change in the future, when extreme climate events are intensified.

Vulnerability to impacts. Experiences of the last few years have demonstrated that Finnish society is not properly prepared for the impacts of extreme events. Some of these events include:

- storm flooding in central and western Finland in July/August 2004
- sea coast flooding at the Gulf of Finland in January 2005
- meltwater and storm flooding of rivers in Kittilä and Ivalo, May 2005

The immediate damage costs of these events for the road network were considerable.

The costs are normally considered as costs of repair and rehabilitation. However, the total economic loss may additionally include losses due to interruption of use and losses due to shortening of the lifetime of structures (with more frequent reconstruction work required).

The need for adaptation measures. Adaptation can be seen as a risk and safety assessment considering:

- Contingency planning (emergency planning and warning)
- Structural improvement to limit and prevent damage and to preserve the service level in existing transport infrastructure
- Improving design criteria of new constructions (e.g. to account for design wind speeds, flood levels, etc.)
- Improving building regulations, guidelines and recommendations

All this requires a better knowledge base consisting of reliable statistics on the occurrence of significant climatic phenomena. Processes leading to damage should be investigated to identify the basic mechanisms and critical details that should be improved. Cost studies should cover total costs, including costs to users through traffic stoppages, depreciation and increased maintenance costs, as well as normal repair and rehabilitation costs.

For critical climatic variables, warning systems should be considered to enable early and proper preparation for extreme conditions. Adaptation to climate change resembles protection planning against acute hazards such as fire, earthquake, tsunami, or storm.

Research needs. Research needed to improve the capacity to adapt to climate change includes:

- Documentation and technical and economic analysis of damage processes obtained from actual damage cases
- Compilation of statistics of available climatic data on critical parameters (storm rainfall and its profile, wind loads, temperatures) and the estimation of future changes in extreme values and their probability of occurrence
- Analysis of statistics on regional flood levels and occurrence, especially along unregulated watercourses
- Development of preventive measures against damage for acute hazards
- Development of more efficient solutions for the design and construction of transport structures (e.g. drainage, stability, erosion control)
- Development of sustainable road maintenance techniques considering climate change (monitoring and prevention of icing, actual measurements of freeze-thaw)
- Development of efficient methods for evaluating and monitoring terrain conditions over large areas
- Development of early warning systems for critical weather events.

1. Background

1.1. Climate change – impacts on transport and the need for adaptation

Climate is an essential part of our living environment, and it has set constraints on human and cultural development. When discussing climate change, we normally mean the change of average and extreme conditions due to a system impact that may be of human or natural origin. A change in climate is the difference between two climate states. In the context of projected climate change, this refers to differences between present-day and future climate states. The actual state is characterized using historical observation statistics, and the future is conventionally described using results from simulations with climate models. As such, the results may offer guidelines for assessing possible futures that should be considered in planning and decision making.

The influence of climate on various elements of the built environment is illustrated in Figure 1. Climate is anticipated to change for natural (e.g. Eronen and Olander, 1990) or anthropogenic reasons. The latter have been dealt with in scenarios. Climatic components can be predicted from model simulations, and the predicted loadings on buildings, infrastructure, transport networks etc. can be inferred using these component predictions.

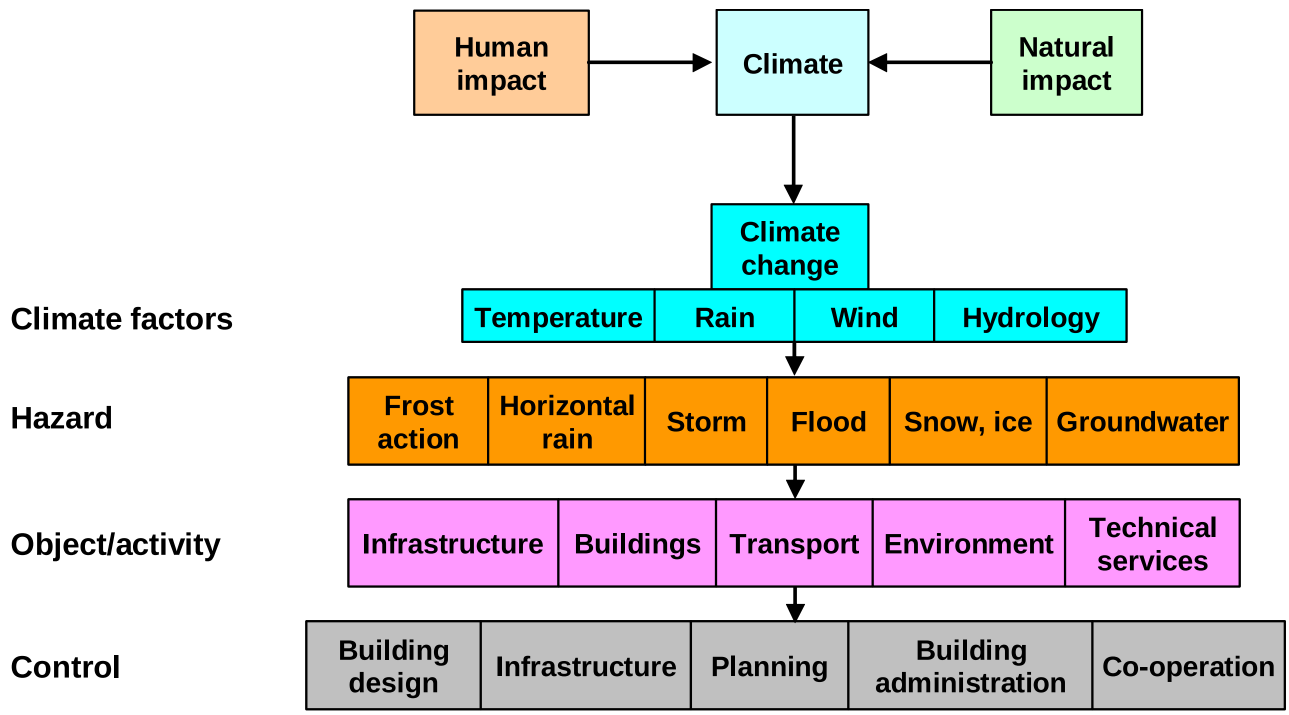

Figure 1. Relationships between climate and the built environment.

The prevailing infrastructure has been designed and constructed to endure the impacts of certain maximal weather effects like frost, rains, winds and flood. These have been determined from historical observational statistics. Adopted design criteria have been estimated on an observational basis, and safety margins are included in the design characteristics of the structures/systems.

The impacts on the safety conditions of use are more complicated: different approaches are applied to prevent or to limit the harm. Examples include winter maintenance of roads and procedures on the railways to control snow and ice problems.

2. Climate change

2.1. Scenarios

At a global scale, climate change may cause large changes in temperatures and in frost and permafrost conditions. This has a major influence on the prevailing communities and infrastructure (UM/YM, 2004; ACIA, 2005).

Scenarios to illustrate projected changes in climatic components have been reported (Ruosteenoja et al., 2005). They are based on different world development pathways which control emissions of greenhouse gases that affect the climate (Carter et al., 2005).

The variations are presented as average changes. For some components, estimates of extremes have been studied, too. The estimated extreme values of, say, the intensity of precipitation, wind speed or accumulated frost or thaw temperatures are important for the limit design of infrastructure. In principle, the frequency of exceedance of extreme values determines the risk level of damage.

2.2. Main components and mechanisms

Rising global temperatures due to the increase of CO_2 and other greenhouse gas concentrations in the atmosphere are the subject of intensive research worldwide. In the FINADAPT scenarios (Ruosteenoja et al., 2005; Carter et al. 2005), the annual mean temperature is anticipated to rise by about 2°C up to 2021-2050 and between 3 and 5°C by 2071-2100 relative to 1971-2000 (Figure 2). This means that in an average year of the 2030s, the conditions currently found at Rovaniemi would prevail in northern Lapland, conditions characteristic of the Oulu-Joensuu region today would prevail in southern Lapland, and contemporary conditions in southern Finland would be found in central Finland (Ala-Outinen et al., 2004).

This implies warmer summers and milder winters. However, it does not mean that there would be no winter – on the contrary, winter weather will still occur with more snow than at present, but during a shorter season and with increased melting.

Projections also show that the occurrence of intense precipitation will increase (Carter et al., 2005; Makkonen et al., 2006). At the same time, in summer the warmer weather and longer rainless periods may lower the water table in groundwater.

Intense rainfall may result in more flooding of natural water courses. It may also exceed the design limits for urban drainage, and the occurrence of flood damage may thus be increased.

Milder winters will also require a change in the profile of winter maintenance in Finland. Nowadays, in southern Finland, the main winter maintenance problem is friction control and, to a lesser extent, snow removal. In central Finland, both friction control and snow removal are important, and in northern Finland, snow removal dominates, because current air temperatures are too low for efficient salting.

In future, friction control will be necessary over the whole country, including Lapland. Snow removal may be required less in the south, but will still be necessary in central and northern Finland. We have to keep in mind that the intensity of solar radiation is practically zero in the winter months, November-February, and heat loss from surfaces cannot be fully and continually compensated by low pressure weather systems and southerly winds.

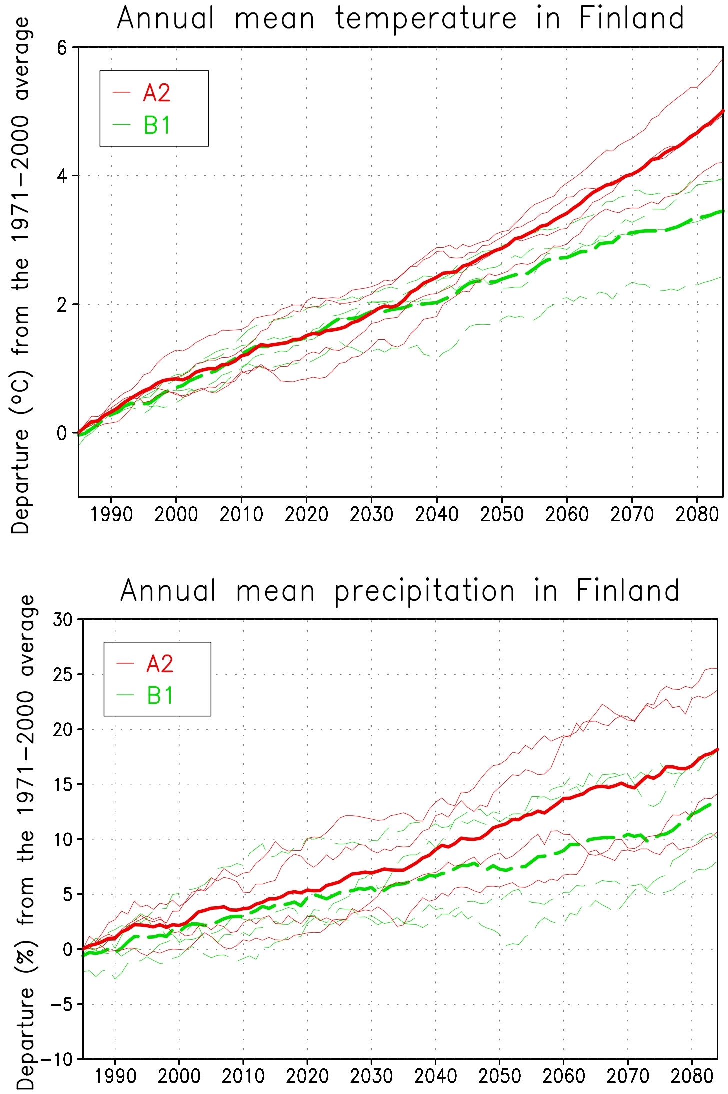

Figure 2. Climate model projections of annual mean temperature (top) and precipitation (bottom) in Finland up to 2085 (thin lines) and 4-model mean (thick lines). Plots are 30-year moving averages relative to the 1971-2000 mean (Carter et al., 2005).

It has also been anticipated that storms and high wind speeds may become more common in the future, though climate model projections differ widely in both the magnitude and sign of change. Water levels in major drainage basins may be changed. If the precipitation increases, the capacity of water courses may be exceeded especially in non-regulated river-lake systems. This could also become a problem in regulated water courses, if the occurrence of very high discharges is dramatically increased. The hydrological aspects are discussed in detail in the FINADAPT work package 6 report (Silander et al., 2006).

The level of the Baltic Sea is expected to rise in line with global sea level rise. This will be more than compensated by isostatic uplift of the land along the coastline of the Gulf of Bothnia, which is expected to continue to exceed the rate of sea level rise through the 21st century (Johansson et al., 2004). However, along the southern coastline of the Gulf of Finland, a reversal from a relative fall to a relative rise in sea level is projected in the second half of the century (Johansson et al., 2004). Extreme high sea levels, which pose the greatest hazard in coastal areas (e.g. the coastal flooding of January 2005 in the Gulf of Finland), result from a combination of extremely low air pressure and strong and prolonged westerly wind in the Gulf of Finland and southerly wind in the Gulf of Bothnia .

Components of the weather may form important combinations that are significant for the use and life-cycle of buildings, infrastructure and transport networks. Such are, for instance horizontal rains (rains during storm winds), which means that the rain hits the structure in a more horizontal direction instead of vertical.

3. Traffic, transport and communications in Finland

3.1. General

Finland's Climate Change Adaptation Strategy (MMM, 2005) contains several sections on the transport sector. Here, sections 3-5 summarise the major findings.

Transport systems consist of traffic routes, terminals, traffic control systems and traffic services. They are planned, constructed and maintained so that their accessibility, condition, safety, undisturbed use, and service level as well as consideration of environmental aspects correspond to the needs of the society. The goal is to maintain and develop traffic routes. Moreover, the goal of traffic policy is to improve the conditions and services of traffic in general, improve traffic safety, protect the service level of commercial shipping, and to protect the competitiveness of shipping relative to primary competitor countries.

The total value of all traffic routes and terminals is about 30 billion Euro of which the state controls about 19 billion Euro. The total length of traffic routes is about 470 000 km. Traffic routes consist of public roads, streets, urban roads, private roads, railroads, water routes, metro lines and tramways. There are 27 airports in Finland (Table 1).

Table 1. The length of traffic routes in Finland (MMM, 2005).

Traffic routes	Length (or number)
Public roads[1]	78,137
Highways	8,574
Principal roads	4,686
Other main roads	28,437
Local roads	36,441
Bridges	13,979 (number)
Private roads[2]	350,000
Bicycle routes[3]	11,000 (in connection with public roads 4,508)
Streets	26,000
Railways[3]	5,836
Waterways[3]	16,000 (fairways maintained by the Finnish Maritime Administration
Number of airports[3]	27

[1]Public Roads of Finland 1.1.2004. Finnra Statistics 2/2004.
[2]Publications of the Ministry of Transport and Communications 8/2004 (in Finnish): Strategy for the development and maintenance of Finland’s transport infrastructure in 2004–2013. Background study.
[3]Finland’s Third Report under the Framework Convention on Climate Change, 2001.

3.2. Roads

Finnish traffic is estimated to grow by about 24% during the period 2002-2030. The most popular means of travelling is the private car (74% of trips). In 2002, haulage of domestic goods in Finland totalled about 41.9 billion tonne-kilometres (t-km), the share of road traffic was about 29 billion t-km (69%), railway transport 9.7 billion t-km (23%), ship transport 2.9 billion t-km and timber floating 0.3 billion t-km (1%). A significant share of road haulage was timber transport.

3.3. Railroads

The railway network in Finland is the densest in Europe, calculated per capita. Railways form functioning connections for personal traffic between regional centres and cost-effective and punctual freight transportation.

3.4. Sea routes

Sea traffic is the most important transport means for foreign trade in Finland. 90% of Finnish exports and 70% of imports are transported by sea. The ports are small, scattered along the sea coast. 23 ports are open all year round; ports on the Gulf of Bothnia need ice-breaker support for about 6 months per year and on the Gulf of Finland for about 3 months.

3.5. Airports

Air traffic is of crucial importance for international connections in Finland due to its remote location. In 2003, more than 13 million passengers passed through airports. Air freight was about 14% of the export value. 95% of international air traffic was concentrated at Helsinki-Vantaa airport.

3.6. Communications

Communication networks are divided in broad band, mobile phone and television networks, the authority net (VIRVE) and telecommunications. The quick, safe and functioning communication networks are a requirement of a productive, competitive, and socially and regionally equal knowledge society.

4. Climate change impacts on transport

4.1. Traffic behaviour

The impacts of climate change influence the whole of traffic system, with impacts varying according to the exposure to climate (Table 2). Road traffic is affected by winds, storm rains, and icing. The anticipated shortening of the ice-free period on the sea may increase the risk of severe wave action. Both sea and air traffic may be more often disturbed by climatic extremes (winds, storms, tornadoes) and general insecurity among passengers using these modes of transport may increase as a result.

4.2. Infrastructure

The climate-based design of traffic facilities is based on certain, approved limit values and loadings. The design standards of both roads and railroads may not be applicable in the future. Increasing precipitation causes a rise of groundwater levels. Storm rains increase erosion of roadside slopes and bridge cones. The service level of roads is disturbed due to rising groundwater. The drainage ditches, bridge openings and culverts do not let through large rains. The failure risk of railway tracks and roads is increased with increasing rains and erosion by flooding. The denser occurrence of storms may cause new demands for port- and airport structures and communication networks based on aerial lines. Risks may concern also safety facilities of sea traffic (strong winds, increased pack ice). Increased occurrence of extreme climate phenomena will, anyhow, increase the service and repair needs of communication networks.

Table 2. Summary of the anticipated climate change impacts on traffic in Finland. Impacts are not comparable, and one cannot conclude which of the described problems or advantages are more significant. Some of the impacts are clearly positive or adverse, but in many cases, the character is so far unclear or depends on the scale of the climate change (MMM, 2005).

Disadvantage	Direction of the impact unclear or a simultaneous disadvantage and advantage	Advantage
– The risk of collapse of railway beds and roads will increase – Floods and heavy rains will damage the structures of road and rail networks, maintenance problems could be expected particularly on gravel roads – The functionality of drainage arrangements based on today’s design will be endangered – Bridge and culvert structures are designed to convey present waterflows – Problems may be caused to railway and navigation safety equipment – Difficult weather conditions will increase in all forms of traffic (road, rail, sea, air) – The sensitivity of traffic to disturbances will increase – The rectification of and preparation for functional disturbances will impose additional costs – Increased need for anti-skid treatment all over the country; for example, the need to apply de-icing salt to roads will extend to the north – Potentially increasing formation of pack ice and thick sludge belts will impair marine traffic – Windiness, storms and heavy rain will cause damage to overhead cable networks and breaks in underground cables	▪ The impacts may change the attractiveness of different forms of traffic ▪ The need for de-icing salt will increase in some places and decrease in others, so the total cost is unclear ▪ Ice and snow conditions may vary significantly between years	+ Shortening of the ice covered period will bring savings in navigation and harbour maintenance costs + Thinning of the snow cover and shortening of the snow period will bring savings in winter maintenance to the road and rail network and at airports

4.3. Maintenance and level of service

Changes in the length of snow period as well as the snow thickness influence on the winter maintenance operations of roads, railways and airports. The current winter maintenance in southern Finland is weighed to ice control, and less to snow removal, whereas in northern Finland the main problem is snow removal. In central regions, both ice control and snow removal are needed.

Thus, rising winter temperatures with increasing precipitation in southern Finland imply a shorter winter maintenance period, and more temperature cycling around 0°C. Thus, more salting may be needed (Ala-Outinen et al., 2004). Winter maintenance in northern Finland involves more snow problems, and also ice control (salting), with the winter period becoming shorter as well. An increase in icing risk may mean problems to rail traffic and airports as well.

Icing risks will require better monitoring of friction conditions on roads and railways. The more frequent winter problems may cause more problems to the road transport and traffic flows. In order to monitor the status of real road conditions, the services of road weather stations will be required. Moreover, an increasing frequency of storms may cause falling trees and broken communication and electrical lines, causing various risks for safety and operations.

Warming winters may cause less frost action, frost heave and damage, as well as a shorter thaw period. However, freezing and thawing will probably become more problematic in the future, and need proper consideration and treatment. The utilization of frozen ground for transport may be constrained to a shorter period with shallower frost depth. Spring thaw problems on low-volume roads will remain a factor in the future.

The risk level is at an optimum, if the cost for preventive measures is no higher than the damage, disturbance and life-cycle cost, compared on an annual basis. A lower risk level means that the service may be maintained with a more expensive maintenance (including an occasional repair).

The frost problems on railroads are similar as today, and need for frost protection is prevailing. The stability of embankments may become more critical with increasing storm rainfall. Rising summer temperatures may cause more problems in settlements of soft subsoils and temperature deformations of rails in hot weather.

In sea traffic, the thinner ice cover and shorter ice period improves the safety of the sea traffic, and reduces travel times. Cleaning of oil spills becomes easier. With less ice, storms may become more frequent. In the conditions of the Gulf of Finland, an increase in traffic would require a more comprehensive sea traffic control system.

Although ice conditions are expected to become less severe, with a diminution of continuous ice cover, the conditions are still problematic because of pack ice driven and piled up by winds. In communication networks, the interruptions caused by storm winds may become more frequent, requiring increasing repair and maintenance. Similar problems may be caused by breaks in electricity overhead lines supplying the base stations of mobile phones.

4.4. Damage cost

Economic impacts due to climate change can be divided into:

- immediate damage repair and rehabilitation cost
- cost for interruption of use
- costs due to value loss (shorter service life, hidden repair needs, higher maintenance need).

Although the compensation or repair investment of flood damage may cover the immediate costs, total costs should be considered in the decision-making and optimization.

In normal discussion, only immediate costs are considered. In transport and communication networks, interruption of use is widely scattered, and a compensation subject cannot be identified. Concerning life-cycle effects, the life cycle characteristics are not so well known that the hidden losses could be economically quantified.

A certain margin for unexpected events is built in to the annual budgets of the Road Administration, Railway Administration, Sea Transport and Air Traffic. So far, this has been sufficient in normal conditions. After unexpected damage, more resources have been used for rehabilitation.

5. Adaptation to impacts

5.1. Principles

Adaptation can be seen as a risk and safety assessment considering:

- Contingency planning (emergency planning and warning)
- Structural preparation to limit and prevent damages and to maintain the service level in existing infrastructure
- Improvements to design criteria for new constructions (design wind speeds, flood levels, etc.)
- Improvements to building regulations
- Emergency investigations and planning of important technical services.

All this requires a better knowledge basis consisting of reliable statistics on the occurrence of significant climate phenomena. Processes leading to damage should be investigated to identify the basic mechanisms and critical details that should be improved. The costs of damage should be related to the costs of improvement in damage cases, to get an idea of optimum solutions.

For critical climatic parameters, warning systems should be considered to enable early and proper preparation. In this respect, adaptation to climate change resembles protection planning against acute hazards like war, fire, earthquake, tsunami, storm, etc.

Some adaptation actions will be required in anticipation of future climate changes (Table 3). These actions should be based on research knowledge. The basis is the knowledge on the vulnerability of the current systems, and estimated change of risks under the changed climate parameters. The increased damage risk, for instance, influences on the economic service life of transport structures.

The sustainable functioning of a transport system requires its adaptation to environmental and climatic conditions. For that reason design criteria that consider climatic impacts in general should meet the anticipated impact levels. The design criteria may need to be periodically checked in the light of ongoing occurrences of impacts and damage. At the same time, new, more efficient solutions for roads and other traffic structures should be studied, experimented with and implemented. It is especially problematic to determine the need to improve current transport structures for higher climatic loadings (storm rains, storm winds, winter conditions, ice cover, etc.). Although all the current roads and transport lines cannot be improved immediately, provisions for limiting or preventing damage and disturbance should be analysed and planned. The vulnerability of transport infrastructure can be decreased with effective maintenance and focused improvement of sensitive objects.

5.2. Adaptive capacity in transport infrastructure

Proactive adaptation can be carried out by administrators on the traffic sector, but a basic requirement for correct applications is consistent information and knowledge. Adaptation requires that climate change impacts be factored-in to long-term investments like transport routes and systems. Their life cycle is tens of years.

In long-term plans for the transport sector, changing conditions should be considered with a long run perspective, hence requiring a modification of the principles of new construction and repair, towards consideration of increased risks, rather than learning only after catastrophic failures. Risks can be considered and optimised, if they can be interpreted in terms of economic losses.

Table 3. Summary of indicative adaptation measures to climate change in transport and communications and preliminary timing (MMM, 2005). *Immediate: 2005–2010, **short-term:2010 –2030, ***long-term: 2030–2080

		Anticipatory	Reactive
Public	Administration and planning	• Inclusion of climate change in the transport sector's long-term planning* • Securing the functionality of telecommunications networks (wired networks) **	
	Research and information	• Surveying of flood sensitive areas* • Anticipatory systems and warning systems for extreme events** • Assessment of the ice situation in the Baltic Sea*	
	Economic-technical measures	• Maintenance of the structures (road body, ditches, bridges and culverts) and condition of road network, particularly on smaller roads and gravel roads as floods and rains increase and ground frost diminishes** • Maintenance of the structures (railway beds) and condition of railways while floods and rains increase and ground frost diminishes** • Minimising the environmental hazards caused by anti-skid treatments (alternatives to salt, planning of groundwater protection)**	• Taking more difficult traffic conditions into account in planning and schedules • Repair of storm damage to overhead cables • Increase of winter traffic in the Baltic Sea • Anti-skid treatment of roads and airports • Repair of storm damage to the road and rail networks
	Normative framework	• New planning norms and guidelines for road and railway construction**/***	• Guidelines and definition of tolerances for the duration of disturbances
Private		• Maintenance of the structures and condition of the private road network as floods and rains increase and ground frost diminishes**	• Taking more difficult traffic conditions into account in planning the schedules and timing • Salting and anti-skid treatment of roads

5.3. Possible proactive measures

5.3.1. Transport routes

The vulnerability to flooding should be investigated to determine the risks and necessary improvement measures. Areas of high flood risk should be avoided in the planning of new routes, and measures to prevent or limit flood impacts should be considered (MMM, 2003).

Drainage systems should be designed and improved to meet the needs of increased design precipitation. New methods of drainage design and planning should be introduced and tested. New construction technology needs to be developed . Special attention should be paid to erosion protection of embankments, slopes, drainage ditches and shoreline structures.

Telecommunication lines, where possible, should be replaced or newly installed underground rather than overhead.

5.3.2. Maintenance

The flexibility of using different transport modes should be increased.

Major changes in maintenance are expected in winter for snow and ice control. The management of friction conditions on the road should be developed further, introducing more up-to-date measurement and modelling systems that facilitate minimising salting and improving traffic safety. This may be beneficial for airports, too. It may also be possible to improve friction control on railroads in the same way.

Operational readiness for exceptional weather conditions should be improved through specific studies and proper planning. These should be designed to minimise delays and maintain a reasonable service level for scheduled traffic. For sea transport, ice conditions may be relieved in general, but the presence of pack-ice and sludge may cause severe problems for shipping.

Air traffic has to adhere to strict air safety control regulations regarding weather effects, and for sea traffic, control and guidance systems should be introduced.

Overhead telecommunication cables are vulnerable because of the risk of falling trees and even flooding. Thus using wireless air communication systems as well as subsoil cables decrease risks. The importance of good telecommunications is emphasized during critical situations.

5.4. Research for adaptation

Changes in the climate in Finland are expected to be significant, and knowledge on the quantity and variation of the change will become more precise as climate research improves. Some natural features are characteristic in Finland: sparse, scattered habitation, long distances, distinct variation of seasons and specific geology and hydrology. These need special attention and nationally-designed solutions.. Transport systems should be studied as a whole, considering the needs of the national economy and policy. Strategies for development and adaptation for different transport systems should be planned to determine the specific measures necessary to improve adaptation to global change. Important impacts are eg. increasing storm rains, floods, storms, winter climate and various extreme climatic events.

The research needs can be listed as follows (MMM, 2005):

- Sensitivity and vulnerability of different transport sectors to climate change impacts
- Change in snow conditions in different regions
- Consideration of the changing extreme phenomena in the design values of transport routes and connected facilities
- Needs for changing the design procedures and structural principles of structures (roads, railways, bridges etc.)
- Observation of extreme weather phenomena and preparation for them in air traffic
- Development of ice conditions in Finnish seas in real time and in long term

6. Cost risks due to impacts

6.1. Recent examples

6.1.1. Example 1. Late July 2004, heavy rainstorm

According to the Finnish Meteorological Institute, rainfall was particularly abundant on 27 and 28 July 2004 in the provinces of Uusimaa, Häme, Central Finland, Savo and Oulu, where 48-hour aggregate precipitation exceeded 100 millimetres at many locations. Such accumulated rainfall was as much as double compared to the average monthly precipitation in July. Heavy rains caused severe damage on roads in central Finland and northern Savo. Parts of gravel roads in central Finland collapsed and 3–4 roads were cut off (Figure 3). The level of the River Vantaanjoki rose by 177 cm due to rain, and several roads had to be closed down for traffic. According to Finnish Road Administration's estimates, the repair of road damage may rise up to two million euros. These cost estimates included neither costs caused by disruption to the use of facilities nor secondary or long-term costs (value reduction, shorter life period, higher maintenance).

Figure 3. Flood on Ruotaanmäki road at Pielavesi, central Finland, in July 2004 (Photo J Kohonen)

6.1.2. Example 2. Early August 2004, heavy rainstorm

In the first week of August 2004, a heavy rainstorm occurred in the region of Vöyri and Oravainen, north of Vaasa, extending from the Kyrönjoki region to Pietarsaari. More than 100 mm of precipitation fell within one day. Damage was centred on the Vöyrijoki watershed. This river is unregulated, seldom floods, and its flood protection level was technically substantially lower than in the nearby watersheds of Kyrönjoki and Lapuanjoki rivers, where, despite the heavy rain, no damage was mentioned in the media.

The rains caused heavy flooding within the Vöyrinjoki watershed and damage to buildings and roads. Immediate damage costs were estimated for the roads to be about 200 k€. Trunk road number 8 was out of service for several days. The excess costs for transport and traffic have not been estimated.

6.1.3. Example 3. Mid-January 2005, sea level rise on the Gulf of Finland coast

A deep low pressure and prolonged, strong westerly winds (up to 28m/s) caused a rise of sea level along the coast At Turku, the level was about 1.3 metres above normal, in Helsinki about 1.5m and at Hamina about 1.95m. The levels were the highest observed since the start of observations in the 1870s.

The flooding caused numerous disturbances for traffic on lowland roads, and required minor repair works due to erosion, slope disturbance and damage to road equipment. The immediate rehabilitation cost was within the budget frameworks for such events, and they were not separately investigated. Influences in the urban areas were more severe.

6.1.4. Example 4. Late May 2005, flooding due to rapid snowmelt and storm rainfall, Lapland

A rapid snowmelt and heavy rainfall caused the discharge to increase heavily in the rivers of northern Lapland. At Ounasjoki and Ivalojoki, the water levels rose more than 2 metres above normal flood levels, causing flooding on main roads and of buildings and infrastructure in the villages. The repair and rehabilitation costs for the public roads totalled about 890 000 €.

6.2. Discussion

The events described above were flooding events, caused by storm rainfall, snowmelt or sea level rise. Other impacts, such as falling trees on roads, are quite common during storms. This is also a common problem for overhead cables used for telecommunications and electricity distribution.

The current risk level depends on the provision of applied technology to the climatic impact. Structures (buildings, roads, service networks) have been designed and constructed considering certain intensity levels of weather events (precipitation, wind speed, temperature, etc.). If the levels are exceeded, then disturbance or damage will result, which grows with rising intensity of the event. The cost of disturbance or damage is not normally known, because these design criteria have been determined based on other principles than damage costs.

7. Adaptation in design and construction

There are different aspects to be considered in adapting design characteristics and construction works to climate change, or to exceptional weather events in general:

- civil protection (preventive measures, protective planning, provisions), which involves measures to prevent acute damage to property and risk of lives under current conditions. This concerns, for instance, preparation of temporary flood-guiding walls, pumps, planning for rescue operations, flood protection with earth dams, regulation of discharge using flood reservoirs, applying alarm systems etc.

- change of design and construction criteria and methods, which requires implementing changes in design considering new impact levels, applying more adequate design methods, and improving the adaptation of structures to impacts.
- administrative regulation and control, requiring decisions on the safety level and criteria of the design of buildings and structures (like the design wind loads), responsibility of organizing the compensation and insurance for damage, general development of knowledge and awareness.
- research and development, aside from research on climate change, this implies the investigation and analysis of circumstances leading to damage and costs, as a basis for improving technology.

8. Documentation of climate change impacts on the transport infrastructure

This section lists some basic data required for documenting impacts of climate change on the transport sector.

For the analysis of damage processes, the following is required as an input:

- Investigations concerning the extent and severity of damage
- Evaluation of the reasons for the damage (weather event, damage process)

Repair and rehabilitation management requires the following tools:

- Measures to limit damage
- Rehabilitation technology
- Planning for the repair
- Improvement of the facility

Proactive measures for the maintenance of infrastructure under a changing climate includes:

- Inspection of structures and drainage
- Precautionary improvement
- Material and instrumental provision
- Planning of alternative routes

Documentation of damage caused by extreme weather events:

- Documentation has not been systematically organised
- Technical and economic data should be investigated, collected and analysed
- Interruptions of use and their costs to transport should be estimated
- Indirect defects should also be investigated (eg. increase of roughness, rutting, permanent deformations)
- Characteristics of the weather event (like precipitation and flood level data) can be analysed after the event
- Utilization of damage documentation data
- Evaluation of damage cost risks
  - Damage cost vs. intensity of event
  - Occurrence frequency of the event
  - Damage cost
  - Probable total damage cost/event
  - Duration and cost of transport interruption
  - Depreciation cost (i.e. shortening of lifetime)

- Optimisation of drainage systems
  - Damage cost vs. rainfall intensity
  - Facilities needed to prevent the damage
  - Cost of improvement
  - If the annual cost due to improvement is less than the anticipated annual damage cost, the investment is profitable

Early warning systems:

- Warning, for example when storm rainfall is forecasted to exceed 50 mm
- Warning of strong wind
- Flood warning
- Planning of emergency protection measures

9. Themes for research and development

9.1. Research needs

Climate change:

- Statistics of available climatic data on critical parameters
- Statistics on occurring regional flood levels, especially along unregulated watercourses
- Estimates on future changes in extreme values and probability of occurrence

Documentation:

- Documentation and technical and economical analysis of damage processes in actual damage cases

Contingency planning:

- Development of preventive measures against damage for acute hazards

Sustainable construction in a changing climate:

- Development of more efficient design procedures and solutions for design and construction of transport structures (drainage, stability, erosion control)
- Determination of regional flood levels for traffic systems
- Development of efficient methods for invention and monitoring terrain conditions in large areas

Maintenance operations:

- Development of sustainable route maintenance techniques considering climate change (monitoring and prevention of icing, actual control of freeze-thaw)
- Development of early warning systems for critical weather events
- Development of efficient control tools and systems for sea traffic to improve safety

9.2. Winter maintenance of transport routes

Climate change of importance:

- Increase of precipitation mostly in winter months
- Precipitation during early winter in the south as water, in the north as snow

Impact on maintenance:

- Maintenance costs of roads and streets increase
  - Snow removal and friction control increase especially in northern Finland
  - Warming of early and late winter may decrease costs
  - Change from today may be small
- Increase in friction control results in more salting
- To reduce pollution, salt use should be minimised

Themes:

- Improve friction control with better weather and pavement monitoring
- Minimize salting with better thermal modelling
- Change chlorides to organic salts

9.3. Flooding

Climate change of importance:

- Winter rains increase, summer rains may even decrease
- Winter flooding more frequent, spring flooding earlier

Impacts:

- Flooding on risk sites:
  - Built areas (insufficient drainage)
  - Streets underpasses, culverts
  - Roads, railroads
  - Water courses (shoreline structures)
  - Seashores (sea level rising)

Themes:

- Determine flood levels at river courses
- Determine flood levels at shoreline of lakes
- Design methods of storm water systems should be improved
- Besides pipelines also percolation, basins for runoff delay

9.4. Groundwater level

Climate change of importance:

- Change of precipitation

Impact:

- Risks from rise of groundwater level:
  - Increase in soil moisture content
  - Rotting of wooden structures, corrosion of steel
  - Bearing capacity of road pavements decrease
- Risks from lowering of groundwater level:
  - Settlements of foundations and pavements on soft clay
  - Rotting of wooden piles

9.5. Erosion and landslides

Impact:

- Increase in precipitation causes rising of water levels and growing discharge in water courses, and increase in soil moisture
- Failure risk of slopes increase
- Erosion and landslides become more common
- Erosion of soil at various earth structures like bridges, embankments, culverts etc.

Research themes:
- Mapping and investigation of failure risks
- Control and limiting of construction in risky areas

9.6. Sea level rise

Climate change of importance:

- Isostatic uplift compensates expected sea level rise by different amounts depending on location
- Flooding risk in coastal areas is also influenced by changes in wind speed. Wind speeds would significantly increase in coastal regions.

Themes:

- Implementation of the current recommendations for the setting of flood levels by Ministry of Environment (Ollila 1999; Ollila et al. 2000; MMM 2003)
- flood levels at sea coast should be determined for application at site
- Sites under flooding risk should be mapped
- Construction within sites under flooding risk should be limited

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Documentation page

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Author(s)	Seppo Saarelainen	
Title of publication	Adaptation to climate change in the transport sector	
Parts of publication/ other project publications		
Abstract	The vulnerability of Finnish transport networks to climate change impacts depends on the climatic conditions anticipated in the future and the robustness of the transport systems affected. Most foreseeable impacts are taken into account in the current practice of design and construction, but design criteria may have to be changed in the future if extreme weather events intensify. Experiences during recent years, such as the floods in 2004 and 2005, have demonstrated that the Finnish society is not properly prepared for the impacts of extreme events. Adaptation can be seen as a risk and safety assessment considering: contingency planning, structural improvement, improvement to design criteria for new constructions, and enhancing building regulations, guidelines and recommendations. Research needed to improve the capacity to adapt to climate change includes: (i) documentation and technical and economic analysis of damage processes obtained from actual damage cases, (ii) compilation of statistics of available climatic data on critical parameters and the estimation of future changes in extreme values and their probability of occurrence, (iii) analysis of statistics on regional flood levels and occurrence, especially along unregulated watercourses, (iv) development of preventive measures against damage for acute hazards, (v) development of more efficient solutions for the design and construction of transport structures, (vi) development of sustainable road maintenance techniques considering climate change, (vii) development of efficient methods for evaluating and monitoring terrain conditions over large areas, and (viii) development of early warning systems for critical weather events.	
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Kuvailulehti

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Tiivistelmä	Suomen kuljetusverkostojen ja -laitosten alttius ilmastonmuutoksen vaikutuksille riippuu odotettavissa olevista ilmastomuutoksista sekä kuljetusjärjestelmän herkkyydestä vaikutuksille. Ilmastovaikutukset otetaan jo nykyisinkin huomioon, mutta mitoituskriteereitä voidaan joutua muuttamaan tulevaisuudessa ääri-ilmiöiden voimistuessa. Viime aikojen tapahtumat, kuten vuosien 2004 ja 2005 tulvat, ovat osoittaneet, ettei suomalainen yhteiskunta ole riittävästi valmistautunut ilmaston äärivaikutuksiin. Sopeutumista voidaan pitää riski- ja turvallisuusarviointina, johon kuuluvat: suojelusuunnittelu; rakenteiden parantaminen ; uudisrakentamisen suunnittelu- ja mitoitusperusteiden parantaminen; suunnittelu- ja mitoitusohjeiden tarkistaminen. Sopeutumistoimenpiteiden valmistelemista varten olisi hyödyllistä selvittää: (i) vahinkoprosessien ja vahinkojen dokumentointi ja teknis-taloudellinen analysointi toteutuneissa vahinkotapauksissa; (ii) saatavissa olevan ilmastohavaintoaineiston analysointi koskien kriittisten ilmastotekijäin ääriarvojen toistuvuuden ja suuruuden määrittämistä; (iii) paikallisten tulvakorkeustietojen tuottaminen etenkin säännöstelemättömien vesistöjen varrella; (iv) toimenpiteiden ja teknii-koiden kehittäminen vahinkojen rajoittamiseksi ja estämiseksi äkillisissä vahinkotapauksissa; (v) ilmastonmuutoksen vaikutusten suhteen kestävämpien ratkaisujen kehittäminen liikennerakenteille; (vi) teiden ja rautateiden kestävien kunnossapitomenetelmien kehittäminen ilmastonmuutoksen vai-kutukset huomioon ottaen; (vii) tehokkaiden menetelmien kehittäminen maasto-olojen laaja-alaista arviointia varten; (viii) varoitusmenetelmien kehittäminen.	
Asiasanat	kuljetusverkosto, tiet, ilmastonmuutos, sopeutuminen	
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The vulnerability of Finnish transport networks to climate change impacts depends on the climatic conditions anticipated in the future and the robustness of the transport systems affected. Experiences during recent years have demonstrated that Finnish society is not properly prepared for the impacts of extreme events. For example, there was considerable damage to the road network in flooding during 2004 and 2005. Adaptation to climate change can be seen as a risk and safety assessment considering contingency planning, structural improvements, enhancement of design criteria for new constructions, and upgraded building regulations, guidelines and recommendations. This requires improved knowledge on future climate, on the processes and mechanisms leading to damage, and on the full economic costs of extreme weather events.

Suomen kuljetusverkostojen alttius ilmastonmuutoksen vaikutuksille riippuu odotettavissa olevista vaikutuksista sekä kuljetusjärjestelmän herkkyydestä niille. Viime vuosien kokemukset ovat kuitenkin osoittaneet, ettei suomalainen yhteiskunta ole riittävästi valmistautunut sään ääri-ilmiöihin. Esimerkiksi tulvat vuosina 2004 ja 2005 aiheuttivat merkittäviä kustannuksia tieverkolle. Sopeutumista ilmastonmuutokseen voidaan pitää riski- ja turvallisuusarviointina, johon kuuluvat suojelusuunnittelu, rakenteiden parantaminen, suunnittelu- ja mitoitusperusteiden kehittäminen ja ohjeiden tarkistaminen. Kaikki tämä edellyttää nykyistä parempaa tietopohjaa tulevaisuuden ilmastosta, haittoihin johtavista prosesseista ja mekanismeista sekä sään ääri-ilmiöiden aiheuttamista taloudellisista kokonaiskustannuksista.

This report is also available at the FINADAPT Web site:
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