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The costs of extreme weather for the European transport systems

EWENT project D4

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The costs of extreme weather for the European transport system.
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[Yhteenvetoraportti sään ääri-ilmiöiden aiheuttamista kustannuksista Euroopan liikennejärjestelmälle]. **Marko Nokkala, Pekka Leviäkangas, Kalle Oiva (eds), Anna-Maija Hietajärvi, Juha Schweighofer, Nina Siedl, Andrea Vajda, Spyros Athanasatos, Silas Michaelides, Matheos Papadakis, Michael Kreuz, Thorsten Mühlhausen, Johanna Ludvigsen, Ronny Klæboe.** Espoo 2012. VTT Technology 36. 92 p.

Summary

The purpose of work package 4 of the EWENT project, findings of which are summarized in this publication, is to provide concrete monetary valuations of the impact of extreme weather phenomena on the transport system. This target is operationalized through several steps of research activities:

- Review of methodologies used to value accidents and travel time savings
- Determination of values used
- Justification of values chosen
- Calculations of impacts, measured in euro
- Mode by mode analysis of what cost items are significant
- Analysis of data availability and needs for additional data for future analysis.

The review of methodologies has shown that there is a solid economic foundation for the methodologies used, even if the actual ways to carry calculations may differ from country to country. Fundamentally, the value of travel time or accidents has been set by defining the variables that are taken into consideration and need to be updated from time to time to reflect changes in relative prices (cost of living, manufacturing costs, salaries etc.). Independent of which country is reviewed, the analogy of dealing with costs remains the same.

Regarding the values used in WP 4, we can establish a trend based on the well documented unit values in the Nordic countries for both accident and time costs. This means that different types of trips and accidents will have to be addressed across Europe in a unified way, which is done by adjusting figures used by the relative purchase power of consumers as means to take into consideration the local economic conditions in the EU Member States.

The approach taken in this report has attempted to combine current knowledge of the weather phenomena and their impacts with the knowledge and best estimation of the future occurrence of similar weather phenomena. What we have opted for is to keep the current values used in monetary valuations as basis for future valuations as well. Results from operator costs review show that there is not much information available regarding the costs accruing to infrastructure operators, and the information is even more difficult to obtain due to service contracts, where costs of extreme weather phenomena are covered partially by contracts and only

partially by excess payments in the case where contract service provision is exceeded.

Results from review of accident and time costs shows that the impacts of extreme weather are quite different by transport mode. Accidents are the major concern for road transport, where volumes of passenger are large and associated accident costs at the European level amount to billions of euros annually. However, for other transport modes the accidents do not play a significant role compared to road transport, due to the fact that there are less accidents (including aviation, where no fatalities were observed in 2010) and therefore the monetary valuation does not generate major losses.

The picture is very similar for time costs, e.g. costs resulting from prolonged travel times due to the reduction of speed or cancellation of travel due to extreme weather conditions. Aviation in particular is vulnerable to impact of shocks, as the operations on the ground are affected over a longer period of time by delays. Delays and cancellations have a cumulative effect as planes are delayed on subsequent routes by the initial shock and the damage amounts to billions of euros on a daily basis at the European Union level on cases such as cold waves creating snow in Central Europe or strong winds. Closure of airports, such as the case of volcanic ash cloud of Iceland in 2010 creates nearly half a billion euro losses per day to the airline industry. In road transport the time costs are also a relevant factor, as the volume of road users makes the overall impact of interruptions significant as all the road users experience similar delays. There are less significant monetary impacts on other transport modes as the volume of passengers on waterborne transport and rail is lower, but the impact is similar in terms of the time costs resulting from the delays.

Europe will each year face extreme weather costs of more than 15 billion euros, based on our calculations which rely on some strong assumptions. However, we believe that this is the magnitude that should be kept in mind when addressing climate change issues. The good news is that it seems that the global warming will reduce these costs, unless the weather extremes become even more violent than what they are at present. Warming climate will reduce many costs in maintenance and also improve the safety of the transport system. What remains very uncertain, are the counter-effects of warming. This analysis brought very little light on that and we feel that the investigation should seriously go to this direction. Warming might include consequences not yet clearly seen.

The most vulnerable transport system segment also in terms of costs is the road system. This is because of the sheer volume of transports that take their routes via roads. The most significant cost issue is traffic safety on roads. However, the trends point so far to the positive direction and these trends clearly outweigh any extreme weather impacts.

There is a high risk though that the transport system, as the volumes of freight and passengers are growing and the infrastructure capacity is getting scarcer, will become much more unreliable to serve transports-in-time. The time sensitiveness of the system will become a greater issue in the future, if pure transport economic consequences of extreme weather phenomena are looked at. Time losses are

particularly relevant to EU's supply chains. The EU's shippers suffer losses of billions of euros each year due to time delays resulted by extreme weather, and this analysis suggests that these costs are on the rise.

Keywords EWENT, cost, extreme weather, transport system, accidents, time costs, pricing

Yhteenvetoraportti sään äări-ilmiöiden aiheuttamista kustannuksista Euroopan liikennejärjestelmälle

[The costs of extreme weather for the European transport system. EWENT project D4]. **Marko Nokkala, Pekka Leviäkangas, Kalle Oiva (eds), Anna-Maija Hietajärvi, Juha Schweighofer, Nina Siedl, Andrea Vajda, Spyros Athanasatos, Silas Michaelides, Matheos Papadakis, Michael Kreuz, Thorsten Mühlhausen, Johanna Ludvigsen, Ronny Klæboe.** Espoo 2012. VTT Technology 36. 92 s.

Tiivistelmä

Tämä raportti esittelee EWENT-projektin työpaketin 4 tulokset. Tarkoituksena on tuottaa rahamääräinen arvottaminen äärisääilmiöiden vaikutuksista liikennjärjestelmään. Tämän vuoksi tässä raportissa on tehty seuraavat työvaiheet:

- Metodologioiden kartoitus onnettomuuskustannusten ja aikakustannusten laskennassa
- Laskelmassa käytettävien arvojen valinta ja niiden perustelu
- Euromääräisten vaikutusten laskenta
- Liikennemuodoittainen analyysi tärkeimmistä kustannuseristä
- Analyysin lisätiedon tarpeesta tarkempia laskelmia varten.

Metodologioiden arviointi on osoittanut että vaikkakin maakohtaiset arvot ja lasekentamenetelmät vaihtelevat ne perustuvat käytännössä taloustieteen tunnettuihin menetelmiin. Ajan arvo tai onnettomuuskustannusten määrittely perustuu muuttujiin jotka ottavat laskelmien kannalta merkiitävät muutokset suhteellisissa hinnoissa huomioon, ja analogia on sama eri maissa.

Koskien käytettyjä arvoja WP4:n laskelmissa, erityisesti Pohjoismaat ovat hyvin dokumentoineet sekä käytetyt arvot että niiden laskentaperiaatteet sekä onnettomuus- että aikakustannuksille. Näitä lukuja on voitu hyödyntää laskettaessa vaikutuksia koko Euroopassa ja maille joissa ei ole käytössä virallisia arvoja laskemille. Suhteellista ostovoimaa voidaan käyttää sopeutuskeinona eri maiden lukuja vertailtaessa ja laskettaessa.

Tutkimuksessa on pyritty yhdistämään nykyinen tietämys sääolosuhteista ja niiden vaikutuksista arvioihin siitä millaisia vaikutukset tulevaisuudessa ovat. Suurimmassa osassa laskelmia nykyarvoihin ei tehty muutoksia laskettaessa tulevia vaikutuksia.

Aika- ja onnettomuuskustannusten osalta tulokset osoittavat että liikennemuotojen välilläl esiintyy merkittäviä eroja. Tieliikenteessä onnettomuudet ovat merkittävä tekijä, koska matkustajamäärät ovat suuria ja vuotuiset onnettomuuskustannukset ovat yli 10 miljardia euroa sääoloista johtuville onnettomuuksille. Muiden liikennemuotojen osalta vaikutukset ovat huomattavasti vähäisemmät, ääriesimerkkinä kaupallinen lentoliikenne, jossa vuonna 2010 ei tapahtunut yhtään kuolemaan johtanutta onnettomuutta Euroopassa.

Vastaavasti aikakustannuksien osalta ilmailuliikenne on erityisen altis shokeille, koska lentokenttien toiminnot joutuvat pitkällä aikavälillä sopeutumaan lyhytaikaisiinkin äärisääilmiöihin. Näin syntyy kerrannaisvaikutuksia ja kokonaisvaikutukset Euroopassa ovat vuositasolla miljardeja euroja. Koko eurooppalaisen lentoliikenteen peruuttaminen, kuten vuonna 2010 Islannin tuhkapilvien seurauksena tapahtui, maksaa ilmailuteollisuudelle lähes puoli miljardia euroa päivässä. Tieliikenteen kannalta aikakustannukset ovat myös merkittävä tekijä, muissa liikennemuodoissa vähäisemmistä matkustajamääristä johtuen myös aikakustannukset jäävät vähäisemmiksi.

Kaikki vaikutukset yhteenlaskettuina merkitsevät vuositasolla noin 15 miljardin kustannuksia laskelmien perusteella, joihin liittyy tiettyjä oletuksia tietojen puutteellisuuden vuoksi. Suuruusluokka on kuitenkin niin merkittävä että se tulee huomioida ilmastonmuutoskysymysten yhteydessä. Näyttää siltä että ilmastonmuutos tulee tulevaisuudessa vähentämään näitä kustannuksia, elleivät sitten satunnaiset äärisääilmiöt muutu ankarammiksi. Ilmastonmuutos vähentää myös ylläpidon kustannuksia ja parantaa liikenteen turvallisuustilannetta. Lämpenemisestä johtuvia mahdollisia vastavaikutuksia tässä tutkimuksessa ei analysoitu.

Haavoittuvin osa liikennejärjestelmää on tieliikenne. Tämä johtuu yksiselitteisesti teiden käyttäjämääristä suhteessa muihin liikennemuotoihin. Tieliikenteen turvallisuuden odotetaan kuitenkin tulevina vuosikymmeninä parantuvan erityisesti ajoneuvojen turvallisuusteknologian parantuessa.

Haasteena tulevaisuudelle on liikennejärjestelmien ajantasaisen välityskyky kasvavien matkustaja- ja rahtmäärien kuormittaessa liikennejärjestelmän rajallista kapasiteettia. Kasvavat aikakustannukset ovat merkittäviä Euroopan kuljetusketjuille. EU:n tasolla rahtiyritykset kärsivät miljardien tappiot vuosittain aikakustannusten noususta ja on hyvin todennäköistä että nämä tulevat kasvamaan tehtyjen analyysien valossa.

Avainsanat EWENT, cost, extreme weather, transport system, accidents, time costs, pricing

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1. Introduction

The previous work packages of the EWENT project have identified the most harmful weather phenomena by transport mode and by European regions. They have also provided tools to specify the frequency and magnitude of the weather phenomena. In the Deliverable 3 of EWENT on the consequences of extreme weather (Mühlhausen et al., 2011) we have been able to specify key European transport network corridors and nodes by transport mode, which have resulted in several case studies where we have been able to obtain more information about extreme weather phenomena affecting these areas.

Based on this, and the probabilities coming from work package 2 (Vajda et al., 2011), in work package 4 the focus will be on quantifying the impact of these extreme weather consequences in monetary terms.

We are interested in various aspects of the monetary impacts. Firstly, it is of importance to the European Union and its Member States to be able to assess the economic costs of dealing with extreme weather phenomena. Second, we are now also able to assess some potential future implications of the phenomena, given the probabilities assigned in work package 2 for the future states of weather (specified as years 2040 and 2070). Third, the fact that extreme weather does contribute to the social costs in the form of increased number of accidents and delays justifies the increased attention to mitigation of these problems. This will set requirements to infrastructure maintenance, to road user training and to weather related information provision.

To summarise, the purpose and linkages of work package 4 with respect to other work packages is explained in Figure 1. This work package will draw information together from the previous work packages and provide inputs to work packages 5 and 6 dealing with risk assessment and risk management options. What has been established so far has been an understanding of the weather phenomena and their probability. We have also identified the representative European cases to analyse in more detail for each transport mode.

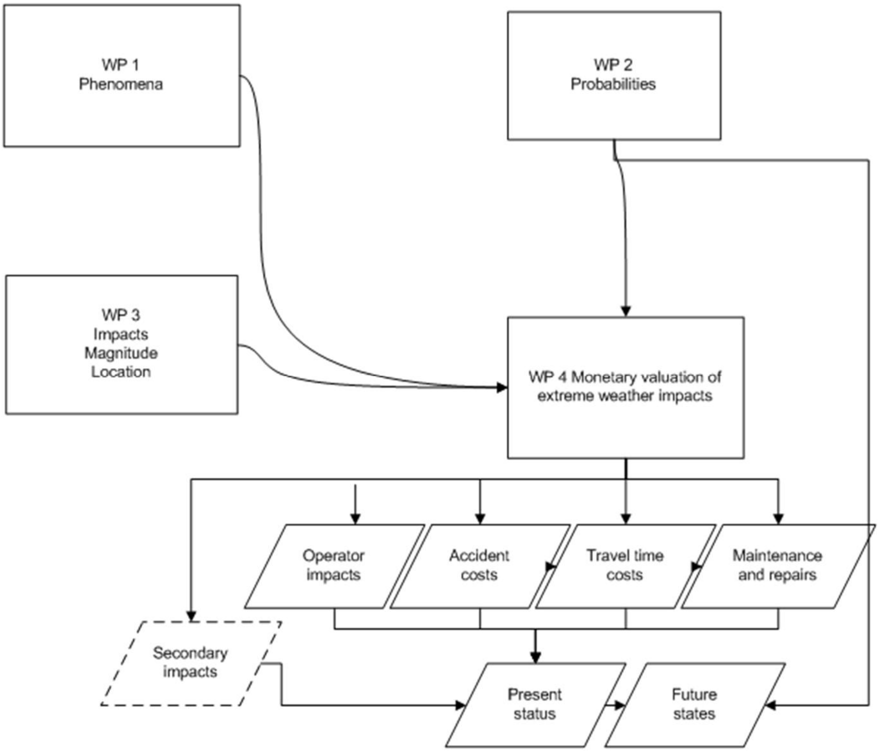

Figure 1. The role of work package 4 in the EWENT project.

The expected outputs of Work package 4 in more broad terms are:

- Estimation of economic costs of extreme weather impacts by selected cases from different climate zones
- Justification for valuation methods and monetary values used
- Overall estimate of potential economic losses in Europe due to extreme weather
- Projection of trend in Europe according to predicted changes in frequency of extreme weather phenomena in the future.

It should be noted, that in Figure 1 we have deliberately used the “operator impacts” rather than “operator cost” term. This is because the impact on operator can also have more abstract features, such as loss of market share, public relations and reputation, training of staff etc. We do not specifically address these features in the cost estimations, neither the secondary impacts (values of insurance contracts, modal shifts etc.).

Sections of this particular deliverable focus on the costs for infrastructure operators resulting from extreme weather phenomena. This is a particularly tricky subject to provide exact calculations, as in many cases the operational arrangements can internalise the costs, at least partially. For instance, in many cases authorities have outsourced service provision to external parties. The contracts between authorities and service providers can take into consideration some degree of extreme events, leaving the rest to extra services category. The authorities may have some estimates of the frequency of extreme events that will be covered by the standard service contract. When such a threshold is passed, additional costs may occur.

We have therefore tried to pragmatically assess the impacts, taking into consideration data from some of the selected case studies. In the lack of comprehensive EU-level data on operators' expenditure on infrastructure maintenance we have to rely on data sources available. We also note that collecting such data would be difficult as unit costs of services vary between different contracts even within a country. Different sectors (transport modes) have also different practises, leading to a complex matrix of contracts and unit prices. For aviation, no analyses were conducted as data were not available.

2. Background, methodology and present costs

2.1 Values of time

2.1.1 Introduction

A review of travel time savings methodology in road transport is provided in Mackie et al. (2001). In transport sector project appraisal, travel time is important in determining road users willingness to pay (WTP) for the investments. It has been considered as an indirect way to value the benefits of new investments to road users. It has also been possible to separate between different types of travel and the marginal utility derived from shorter travel times.

The idea of a value attached to the time assigned to any activity goes back to Becker's (1965) theory of the allocation of time. DeSerpa (1971) was the first to include a set of minimum time requirements for each activity explicitly (analytically). These requirements are depended on the amount of goods consumed. DeSerpa's work can be summarised by recalling the three types of time values that he defined, and the relation he established among them. He postulated a utility function dependent on all goods and all time periods (which he soon called "activities"), including work and travel. The technical constraints established that consumption of a given good required a minimum assignment of time. Within this framework, DeSerpa defined the value of time as a resource as the value of extending the time period, equivalent to the ratio between the marginal utility of (total) time and the marginal utility of income.

A willingness to pay to diminish travel time by one unit is usually calculated from discrete travel choice models, as the ratio between the travel time coefficient and the coefficient of travel cost (if travel utility is linear). This represents the rate of substitution between cost and time for a given level of utility, and is also called the subjective value of travel time.

In the transport project appraisal, the value of time savings is a relatively new component. The calculations of project cost-benefit ratios have taken into consideration other factors more long time, but the foundations of the value of time calculations were laid in the 1960s and 1970s as discussed before, with first official values appearing in the late 1990s[1].

Travel time savings are generated when travel time is reduced. Analogically, travel time costs accrue when travel time are prolonged, for instance due to extreme weather conditions. There is also the society point of view involved in the reduction of travel times. People are considered to be able to contribute more to the society and the economy (Gross Domestic Product, GDP), when they spend less time travelling.

Standard methodologies used in the appraisal are derived from utility theory and social welfare economics. The marginal utility of travel time savings can be expressed as a function of aggregate consumption and time allocations between work, leisure and transport. In terms of considering the European Union wide calculation of travel time costs resulting from extreme weather, the calculations should take into consideration the prevailing differences in purchase power across the region.

In the aviation market there is a wide range of scientific examinations concerning the additional costs for customers or operators in case of delays or even cancellations. One of the best known analyses was published by the Performance Review Commission and carried out by the Transport Studies Group, University of Westminster (Cook et al. 2004). This work aimed to evaluate the true costs to airlines (and customers) of one minute ground or airborne delay. The idea was to not only consider delay costs on a tactical level, which means at the day of operations, but also days/months in advance when e.g. schedules were to be developed (strategic level). Furthermore the appraisal considered the length of delays, the location where the delay was incurred (airborne, ground, taxi, gate) and whether only the initial delay was considered or whether the cost of network effects was included (EUROCONTROL, 2009c). In consequence delay costs at two different levels were determined. According to this work, cost of scheduled buffers or opportunity / sunk costs are examples for strategic delay costs. On the other hand there are primary and reactionary delay costs (tactical costs) that are all calculated as marginal costs. Typical examples for these costs could be fuel, maintenance, ground handling, passenger handling and airport aeronautical/en-route ATC charges.

Another well-known approach for determining delay costs was made up by the Institut du Transport Aérien (2000). Their examination “The Costs of Air Transport Delay in Europe” offers an approach that is based on a cross-analysis according to the concerned economic activities and individuals, and the nature of delay.

The goal achieved by this report is to underline the fact that delay cost are non-linear related to duration. For example, a sixty minutes delay of an aircraft is likely

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[1] We must take into consideration that moving from theory to practise and to incorporate new elements to official project evaluations carried out by government agencies is a long process, which involves stakeholder consultations and testing of the methodology before its application.

to be more cost-intensive than 60 times one minute delay, as sixty minutes delay will have much more disruptive effects concerning crew planning, gate assignments etc.

Compared to the above mentioned examination, the ITA study does not distinguish between airborne and ground delays. Values given by ITA are in consequence a weighted average of the two.

For rail, the standard cost-benefit analysis (CBA) does not have specific values, normal practice has been to use those used in the road transport. This is because the value of time calculations by national authorities already takes into consideration rail passengers, as shown in the examples in the next section.

Similarly to rail, inland waterways do not have an established methodology. For analyses that follow in other deliverables of this work package, we will use the figures from road transport CBA.

2.1.2. Current values of time in Europe

Travel time savings in road transport are based on types of travel defined as euro/person/hour. There are several possibilities to calculate the travel time savings, for instance separating work-time travel, commuting travel and leisure travel. This is done for instance in Finland and Norway (Liikennevirasto 2010; Samstad et al., 2010). Naturally the overall impact is of interest, but typically largest volumes of traffic occur with peak hour commuting, which places a special emphasis to commuting traffic.

At present, the travel time is valued in many countries, as it is a component for the project appraisal cost-benefit analyses in most of the transport sectors. We shall present in this section some of the current values used in the analysis in the European Union Member States.

In **Norway**, the values of time savings have been adjusted by transport mode. Each transport mode (vehicle, public transport, train, boat) have been assigned values of person/hour/NOK (Norwegian Kronor). Values have been assigned for both long and short trips. Since we are interested in the short trips in urban areas or passenger transport we focus on the valuations for short trips. Table 1 presents the values currently in use in Norway in both NOK and euro.

Table 1. The Norwegian travel time values for short trips, NOK (euro) per person-hour. (Source: Samstad et al., 2010)

	Car driver	Public transport	Ferry	Speed boat
Trips to and from work	90 (11.84)	60 (7.89)		
Other private trips	77 (10.13)	46 (6.05)		
All private trips	80 (10.52)	51 (6.71)	126 (16.57)	82 (10.78)
Business trips	380 (49.97)	380 (49.97)	380 (49.97)	380 (49.97)
All trips	88 (11.57)	60 (7.89)		

For travel during the working hours, the valuations will be done according to the average wage of all sectors salary costs. In Finland the coverage of wage data allows to utilise relevant statistics on wages to contrast the road users' average with respective salary data (Liikennevirasto, 2010). The present values used in Finland are based on 2007 wage study and adjusted with wage index to 2009, which is the current base year. The additional costs on top of wages were 22%.

The unit value for working hours travel is 21.70 euro/person/hour. For commuting the value is 9.78 euro/person/hour. For leisure travel the value is 6.22 euro/person/hour.

Commuting travel is valued in the Nordic context using the relationship between commuting trips and other leisure time travel. On trips shorter than 100 km (which is usually considered the commuting distance) the time saving value of commuter trips is 39–68% higher than that of other leisure travel time savings. In Finland the estimation of commuting travel time value is done starting from the salary estimate used for travel during working hours.

Leisure travel is considered at 35% of the base salary excluding the additional cost items. The percentage has been defined to take into consideration the relationship of valuation of leisure time with respect to paid/earnings related travel time.

Professional drivers are a separate category as well. Their salaries in Finland are determined based on the sectors' agreed wage levels and with added factors such as paid holidays etc. The average compensation for truck drivers was 21.41 euro/hour and for lorry 20.28 euro/hour.

In Sweden the unit values also include rail passengers (SIKA, 2009). The unit values for Sweden are reported in Table 2 below. The values are lowest of the countries reviewed, indicating that there are substantial variations between countries that are of relatively same income level. The fact that Swedish values do not distinguish between types of travel is also an interesting feature.

Table 2. Values of time for Sweden, SEK (euro). (Source: SIKA 2009)

	Car, work	Car, other	Regional train, work	Regional train, other
Values of time, SEK(euro)/hour	107 (12.12)	69 (7.82)	68 (7.70)	49 (5.55)

In comparison, the values do differ, with Norway leading the business trips category and less value on non-business travel. Trips using public transport are valued lower than private car usage across Nordic countries, indicating that the income losses associated with travel in private car are higher than those for public transport users.

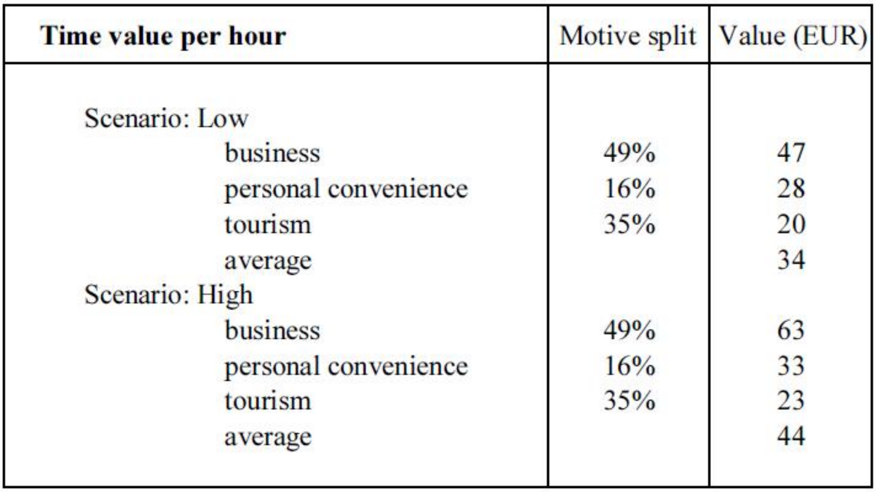
In **Switzerland** the values have been divided as shown in Table 3 below. The Swiss values (König et al., 2004) are relatively highest compared to other countries, which is partly explained by the high GDP/capita of Switzerland.

Table 3. Values of time for Switzerland, CHF (euro) per hour. (Source: König et al., 2004)

	Commuting	Shopping	Official driving	Leisure time
Private car	29.9 (26.38)	25.4 (22.40)	45.2 (39.88)	17.2 (15.17)
Public transport	23.9 (21.09)	19.4 (17.12)	40.3 (35.55)	13.5 (11.91)

Aviation is different from other transport modes, as it has a standard set of values used across Europe. Based on the remarks and literature given in chapter two, the following unit values shown in Table 4 can be as standard values for CBA or other analyses dealing with air traffic related cost studies.

Table 4. Passengers' time values. (Source: Institut du Transport Aérien, 2000)



Time value per hour	Motive split	Value (EUR)
Scenario: Low		
business	49%	47
personal convenience	16%	28
tourism	35%	20
average		34
Scenario: High		
business	49%	63
personal convenience	16%	33
tourism	35%	23
average		44

The bases for these estimations of value of time are multi-modal surveys that have been carried out in European countries according to their travel motive (business, personal convenience and tourism), relying upon various modal split econometric models (Institut du Transport Aerien, 2000).

The number of passengers was calculated using an average aircraft capacity, an estimated number of delayed flights and load factor. The estimated distribution of passengers according to travel motives was applied to the delayed passengers.

Cost per passenger was calculated by multiplying the number of passengers delayed in each category, by the average duration of a delayed flight and the value of time per motive of travel. Adjusting these values from 1999 prices, values of approximately € 43 to € 55 per hour (in average) can be taken as a practical approach for evaluating the loss of time due to delays (Institut du Transport Aerien, 2000).

2.2 Accident costs

2.2.1 Introduction

Similar to monetary valuation of travel time, accident reductions are also considered in the transport project appraisal. In principal, the persons subjective experience of an accident is a theoretical one, as explained later in this section. The monetary valuations are based on unit values, which contain relevant unit values for material and non-material economic losses and damages to property. For different types of injuries the valuations are done according to the consequences, for instance:

- fatality
- permanent injury
- temporary severe injury; and
- temporary slight injury.

The definition of death contains person that have died as a consequence directly or within 30 days of the traffic accident date. Permanent injury is considered to sustain, whereas temporary severe injury can last long but is curable. Slight injury requires some short-term treatment.

The unit value of damage (injury) to a person is formed by several factors:

- administrative costs
- cost outside insurance schemes
- production losses
- loss of well-being.

In addition to injuries the damage to vehicles is also determined. Additional amount is calculated for transport administration's costs.

The actual valuation is based on real economic costs of investments and the lost production value in the national economy. The values are average, and not based on the individual's personal characteristics. This means that for instance the age or the socio-economic status of the person involved in an accident is not a factor contributing to the overall assessment of the damage.

The valuation of life is done by the concept of “statistical value of life”. This is usually counted through the stated or revealed preferences, which implies that persons value their well-being differently and, thus, place a different value to their probability to be involved in an accident. The statistical value of life usually refers to an average working career person in an economy and is not adjusted to the actual person involved in the accident.

2.2.2 Examples of accident costs

To illustrate the process of estimating statistical value of life and other accident costs we use the example from **Germany** (Bundesanstalt für Straßenwesen (BASt), 2011). Economic costs of road traffic accidents consider all accident consequences which result in cost:

- Reproduction costs are incurred to produce through the use of medical, technical, legal, administrative and other measures of technical equivalents of the situation as before the accident.
- Resources loss costs are costs which result from the fact that by accident the injured or killed persons are no more able to participate in the production process. Thus the national product is reduced. Furthermore in traffic accidents vehicles are damaged or destroyed. These vehicles represent special capital which is permanently no longer available in the production process
- Humanitarian costs are consequences of personal injuries, losses lead indirectly to resource consumption. Humanitarian consequences of an accident without loss of resources are not considered in the accident costing. Suffering and grief in consequence of an accident incident are not evaluated.

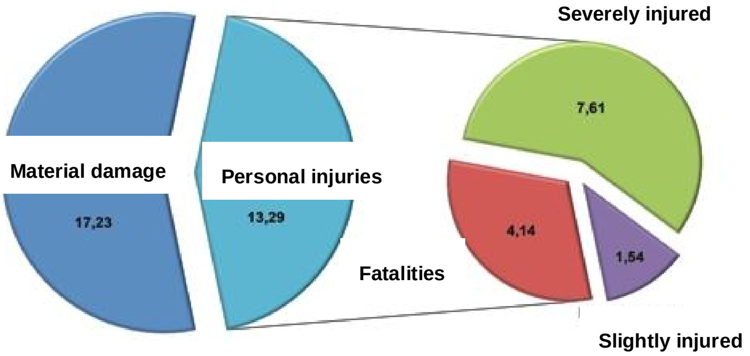


Figure 2. Economic accident cost in 2009 (in billion euro). (Source: Bundesanstalt für Straßenwesen for the year 2009, 2011)

For accidents, there are several countries where the transport cost-benefit analysis (CBA) utilises the official values for accident categories. We shall briefly review some of the figures and present an overview of the official values in use across the Europe.

For **Germany**, BASt (2011) calculates the costs of road accidents with personal injuries and material damage on an annual basis in Germany. The accidents were classified according to their severity: The accident severity is decisive for the overall economic cost. The valuation of overall economic cost of casualties results in 1 161 885 € (fatality), 87 269 € (severely injured) and 3 885 € (slightly injured). The more severe injuries, in road and railway traffic accidents, create a much higher consequential cost per accident than in inland waterway freight traffic (road +141%, rail +100%). The average costs of material damage can also be obtained from statistics. The specific economic cost comprises the human and material costs related to the transport performance.

Average material damage for each road accident can be likewise taken over for the road haulage from the computations (Table 5). For the railway and inland waterway transport appropriate values result from a computer forecast of the damage estimations contained in the conveyed data records to the accident.

Table 5. Accident costs for personal injuries and material damage according to the severity. (Source: Bundesanstalt für Straßenwesen for the year 2009, 2011)

	Value in euros
Costs for personal injuries (each injured person)	
*fatality	996 412
*severely injured	110 571
*slightly injured	4 416
Costs for material damage (each accident)	
*fatality	40 108
*severely injured	19 215
*slightly injured	13 036
*severe accident with material damage	19 365
*other accidents with material damage (incl. accidents because of alcohol)	5 643

For **Finland** (Liikennevirasto, 2010), the official figures for the loss of welfare (excluding the economic costs) are 1 414 629 euro for fatality, 238 420 euro for serious injury and 43 711 euro for slight injury.

For **Norway** (Samstad et al., 2010), the official figures for the loss of welfare (excluding the economic costs) are 3 494 180 euro for fatality, 537 474 euro for serious injury and 62 438 euro for slight injury (converted from original NOK values, exchange rate of June 10, 2011).

For **Sweden** (SIKA, 2009), the official figures are 2 412 000 euro for fatality, 400 000 euro for serious injury and 15 280 euro for slight injury (converted from original SEK values, exchange rate of June 10, 2011).

For values of life, Table 6 below presents an overview of the values in Europe, for those countries for which they were available. These figures are updated from original figures to take inflation into consideration so they may not correspond to published figures entirely. However, they give a good indication of the range of values across the Member States.

Table 6. Official values of life for EU countries. [Sources: updated figures from Sweden (SIKA, 2009), Finland (Liikennevirasto, 2010), Norway (Samstad et al., 2010), Germany (Bundesanstalt für Straßenwesen, 2011) and the Netherlands and for other countries (ECORYS Transport and METTLE, 2005)]

Country	Official values in use (€m)
Austria	1.93
Belgium	0.51
Denmark	0.65
Estonia	n.a.
Finland	1.41
France	0.78
Germany	1.04
Greece	0.18
Hungary	n.a.
Ireland	1.32
Italy	n.a.
Luxembourg	n.a.
Netherlands	1.78
Norway	3.49
Sweden	2.41
Switzerland	n.a.
United Kingdom	1.94

In aviation, besides the mentioned cost for airlines and passengers in case of delays and cancellations, there is the value of avoided fatality that is referred to briefly. Relying on an examination done by the US Department of Transportation in February 2008 the average value per fatality averted is up to € 4.3 million (US Department of Transportation, 2008). A European study by the Norwegian CAA offers values of about € 2.5 million (source: Norwegian Civil Aviation Authority, 1999). These figures are above the road transport figures for most countries and will not be considered in the analyses as for aviation no accident cost calculation is carried out.

2.3 Infrastructure related costs of extreme weather

2.3.1 Defining the cost items

The first notion on defining the cost items of infrastructure costs is that despite the fact they are well known, quantifying them in euros is very difficult. This is because these cost items consist of various inputs in terms of labour and materials. Thus, a repair or maintenance activity is rarely defined in a self-explanatory matter. To highlight this problematic nature, an example can be given:

> *A blizzard results in a tree falling on rail tracks. The exact cost of repairing the track depends on the time, location and severity of the damage. Therefore, to give an estimate of the repair cost would lead to significant interval of euros spent depending on the nature of the precise accident.*

As the market for service provision in the infrastructure sector has become more open for competition over the past decades, it has led to less transparency regarding the actual costs of service provision. Simple questions such as how much 100 meters of tarmac would cost or what is the average amount needed to repair a bridge are not so easy to answer. The industry does not have average rates for such services, even when considered as routine work.

A second and even more challenging factor of determining infrastructure related costs is related to the service model. Whether we are using a traditional model of in-house service provision for infrastructure maintenance by the operator and provider or a client-supplier model does not make as much a difference as does the nature of the service contract itself. In most cases the standard provision of services under the service provision agreement is sufficient to fix the damage. This is normal when a single item causes an interruption in the transport service supply. However, when extreme weather produces impacts that are beyond the standard contract then the challenge of measuring costs becomes imminent. Services and labour provided outside the standard service contract will produce additional cost, which is the result of the extreme weather event.

However, in some cases the costs of maintenance or repair are available, when the costs can be directly related to the extreme weather event. Even in these cases, we should be aware of the distributional effects, i.e. one man’s cost is another man’s revenue.

In road transport, there are several parts of the infrastructure that can become subject to repairs and maintenance as a consequence of the extreme weather. Below is a short summary of the expected repairs and maintenance needs and from which phenomena they result from:

- foundations: low temperature, flooding
- pavements: low temperature, flooding, mudslides, heavy rain
- surface (tarmac): low temperature, high temperature, mudslides
- physical obstacles to be removed: flooding, blizzards, mudslides, heavy rain.

We have to take into consideration the time space where we limit our analysis. For instance, finance costs to companies that need to build up loans to pay for the extra works needed may not directly fall into category of infrastructure related costs for the purposes of our analyses.

In the WEATHER project (Enei et al., 2011, Doll and Sieber, 2011), analyses of the costs to infrastructure were provided. Next section begins with an overview of the work done in WEATHER project and presents some additional information regarding the infrastructure costs.

Table 7. Costs of extreme weather to infrastructure by phenomena and transport mode at the European level, euro million. (Source: Enei et al., 2011)

Extreme weather event		*Infrastructure assets*	*Infrastructure operations*
Storm	Road	76.10	22.60
	Rail	0.07	
	Maritime	–	–
	Air	–	–
Severe winter	Road	248.80	126.30
	Rail	0.04	
Flood	Road	630.10	21.90
	Rail	103.66	

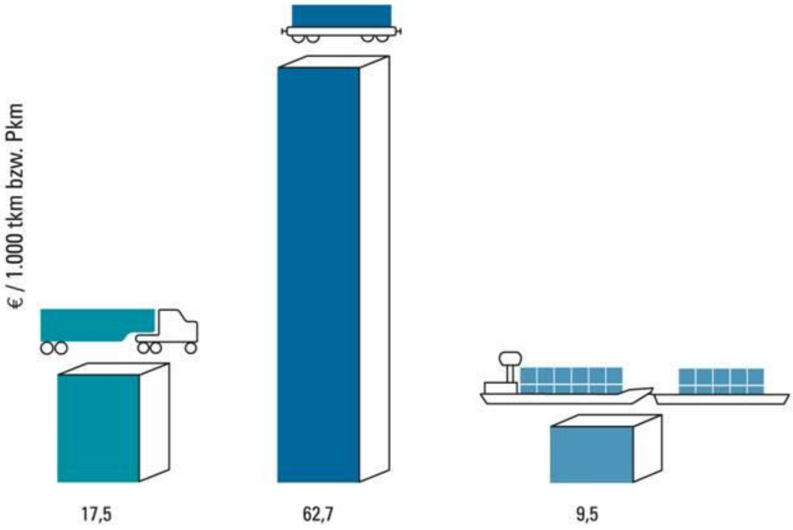
2.3.2 Investments in transport infrastructure

It is in general difficult to get detailed information of the costs of extreme weather to infrastructure at the European level. Enei et al. (2011) present the following information on costs of extreme weather on infrastructure. As the authors conclude:

> *"In some case the annual estimation is the result of the generalization at EU level of cost estimations available for given countries, using specific parameters and variables (traffic flows, number of container, etc.), i.e. for the road and rail sectors, the intermodal transport (freight) and the air transport; in other cases the generalization has not been made possible, as for waterborne transport (inland waterways and maritime). When the generalization has not been made possible, a certain downward bias in the final results must be taken into account. And even when the generalization has been made possible, a certain downward bias is still possible due to lack of information, as for the costs suffered by the rail transport system because of extreme very cold days."*

An example on transport infrastructure investments can be found regarding the inland waterways. The inland navigation vessel offers a number of system-based advantages as a mode of transport. Compared to other modes of transport, inland navigation has the lowest specific energy consumption and the lowest external costs, high transport capacity and, unlike roadway or railway transport, requires little investment for maintaining and improving infrastructure.

Comparably low investment in transit routes and the ports suffices to cope with a part of the strong increase in the transport of goods along the Danube Corridor, as existing capacity can be utilised to a large extent. A study from the Federal Ministry for Transport, Innovation and Technology compares transport costs for various modes of transport in Austria (Figure 3).



Quelle: arealConsult und via donau

Figure 3. Infrastructure costs for modes of transport in the Danube Corridor. (Source: ArealConsult, 2004).

Compared to road or railway transport, the waterway requires the least investment in infrastructure (Table 8). In order to achieve an equal transit output for each mode of transport, € 1 would have to be invested in the waterway, compared to € 1.83 in the roadway and € 6.57 in the railway.

Table 8. Comparison of investment costs: traffic capacity of road, rail and ship in billion t-km and billion person–km. (Source: ArealConsult, 2004)

	Time period					
	2000 – 2020			2000 – 2030		
	road	*rail*	*ship*	*road*	*rail*	*ship*
t-km total	178.725	148.423	88.65	329.571	270.253	180.13
shifting	-9.058	-5.459	–	-27.893	-16.812	–
t-km after shifting	169.667	142.964	–	30.1578	253.441	–
person-km	125.776	42.109	2.41	217.989	64.436	3.91
total t-km + pers-km	295.443	185.073	91.06	519.667	317.877	184.04
investment billion €	5.173	11.597	0.869	5.173	11.597	0.869
€/1000t-km+pers-km	17.509	62.661	9.543	9.954	36.482	4.722

Net investment costs in transport infrastructure in the Danube corridor result in 5.173 billion euros for roadway, 11.587 billion euro for railway and 0.869 billion euro for waterway (ArealConsult, 2004).

A study by the PLANCO (2007) consulting company concerning a comparison of transport modes in Germany calculated the **economic cost per 100 domestic t-km** for the years 2000 to 2005: €-cents 53.1 in road freight traffic, 6.0 in rail freight traffic and 3.3 in inland waterway freight traffic (see Figure 4). So the specific economic costs of the road freight traffic are 16 times higher and those of the rail freight 80% above the specific economic cost of inland waterway freight traffic. The numbers of casualties in rail and inland waterway freight traffic are on a very low level and therefore the costs are fluctuating yearly from 3.8–8.8 €-cents (train) and 2.8–3.9 €-Cents (inland waterway vessel) per 100 domestic ton-km. Anyway, there is no trend recognizable and therefore the average values are representative.

In the road freight traffic, to the contrary, a declining trend in accident and casualty numbers is recognizable. In combination with an increasing transport performance this leads to a continuous decline of the specific economic cost per 100 domestic ton-km from 67.0 €-cents in the year 2000 to 42.9 in the year 2005. Anyway, even when taking this in account, there is still a huge gap compared to rail and inland waterway transport rates. The specific economic cost of road freight traffic in 2005 is 7.2 resp. 13 times higher than the averaged specific economic cost of rail resp. inland waterway freight traffic (see Figure 4).

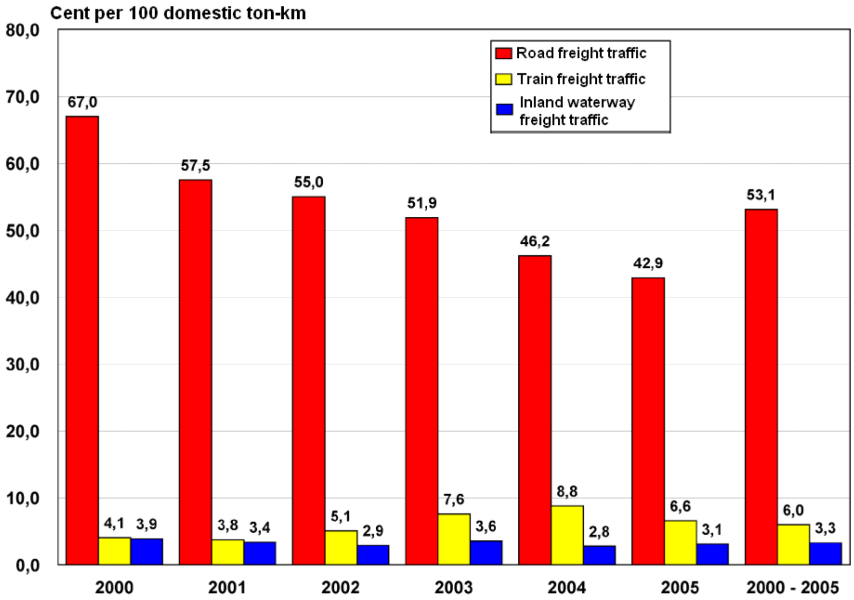


Figure 4. Specific economic cost development in freight transport by road, rail and inland water-way vessel (2000 to 2005). (Source: based on PLANCO, 2007)

2.3.3 Maintenance

From the road sector, we can also obtain some real costs from the winter maintenance in Helsinki region due to extraordinary snow fall in winter 2009/10 and 2010/11. In Figure 5 below the case of city of Vantaa is shown. Figure 5 presents costs of snow blowing and removing shot up, due to the extraordinary winter conditions. This lead to increasing removing costs by 6 times compared to normal winter, and to more than doubling the snow blowing costs.

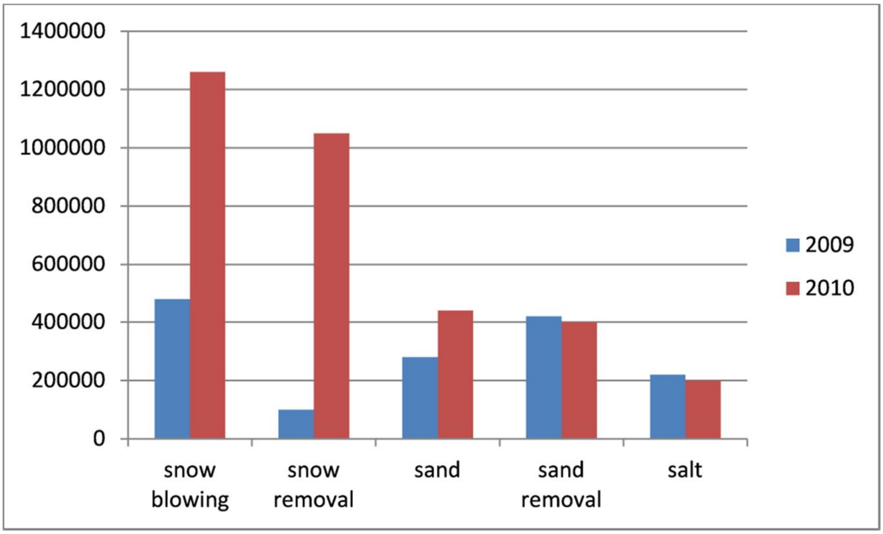


Figure 5. Road maintenance costs (euros) in the city of Vantaa Finland, for 2009 and 2010. (Source: direct information from City of Vantaa)

Similar developments were observed in Helsinki as well. As shown in Table 9 below, the winter maintenance costs over 2 exceptional snowfall winter exceeded the budgeted levels by more than 50%. The budgeted levels represent the typical winters, whereas the exceptional snow fall shows the impact of such events on service contracts. The figures presented here are in line with those reported by Doll and Sieber (2011). In Germany the costs of winter maintenance range between 2000 and 10 000 euros/km on highways, 5 000 euro on motorways and 1 300 euro on 2-lane highways. Figures for Finland are reported in the table below. In sum, these data show that cost variations to the budgeted can in extreme situations vary between 50%–100% even in day-to-day maintenance operations.

Table 9. Winter maintenance costs (euros) in Helsinki city, 2009–2011. (Source: direct information from City of Helsinki)

Winter maintenance	Treasury 2009	2009–2010 (Treasury 2010)	2010–2011 (Treasury 2011)
Budgeted	21 430 000	21 900 000	20 800 000
Actual	21 065 000	30 500 000	35 300 000[*]

[*] forecast covering the early part of year, winter maintenance

Thus, to conclude, the examples available suggest that even when contracts provide a standard service level in maintenance, extraordinary weather results in extra demand of services from suppliers. This in its turn leads to additional services that are outside the original contract. Depending on the nature of the contract the unit costs of these services can be higher or lower than those covered by the standard contract. The more safety margin for extreme weather cases are reserved in contracts, the higher risk premiums have to be covered as well.

In the Finnish national roads maintenance, some unit values for maintenance also exist (National Road Administration of Finland, 2008):

- Winter maintenance: 991 euro/km/year
- Highway maintenance: 3 350–6 063 euro/km/year
- Main road maintenance: 1 595–4 000 euro/km/year
- Regional roads: 530–935 euro/km/year
- Feeder roads: 430–739 euro/km/year
- Light traffic pathways: 412–1 304 euro/km/year
- Supporting infrastructure maintenance: 382 euro/km/year.

Depending on the type of extreme weather phenomena, the operational activities resulting from extreme weather (wind, heavy snow etc.) in some cases cover large geographical areas and, in other cases, only a specific section of the road, for instance in the format of a physical obstacle. It would be possible to develop a model that would capture such maintenance needs in a national scale, analogical to national level accident forecasting models. However, no such models exist at present as the unexpected occurrence of extreme weather events poses a challenge.

2.4 Operators' costs

2.4.1 Port operator costs

One of the sectors where weather can play a significant role in creating delays to operators is the maritime transport. In order to assess the cost of delays/cancellations due to extreme weather on ports, one must bear in mind that each port presents challenges and unique characteristics that make such a calculation difficult. Indeed, a port is a hub of many activities and its economic revenue comes from many different sources. It is safe to say that while the lion's share of port revenue comes from shipment handling (70–90%); even these operations alone are subject to many contributing factors. (Suykens, 1996).

There is no unified picture of ports since each is designed for a specific type of operation, be it a loading/unloading procedure or the type of cargo handled. Considering the first factor, there are two basic methods of loading and unloading cargo to vessels. They are *lift on–lift off* (Lo-Lo), which refers to the loading and unloading method, employing either the vessel's gear or quay-side cranes, and *roll on–roll off* (Ro-Ro), which refers to the loading and unloading method conducted by horizontally moving equipment. Vessels allowing this type of loading and unloading are equipped with a loading ramp that permits the movement of cargo handling equipment and other vehicles (trucks, forklifts, straddle carriers, tractors, etc.) between quay and vessel.

A second factor that makes such a calculation difficult is the type of cargo: passengers, dry bulk, liquid bulk, containers, etc. At cargo ports, the type and packaging of cargo products determine the manner of loading and unloading as well as the type of other operations involved.

The following basic categories of port terminals can be identified, each having varying equipment and operational features:

A) *General cargo terminals.* These are terminals equipped with conventional cranes, which handle cargo in all types of packaging compatible with cranes. The packaging could be parcels, sacks, pallets, or containers. The latter should not, however, constitute a major percentage of the traffic, because otherwise a specialized container terminal would be required to improve throughput performance.

B) *Container terminals.* In this case, containers are handled using special loading/unloading, transfer, and stacking equipment. They are typified by extensive yard areas for container stowage.

C) *Multipurpose terminals.* These terminals combine a variety of functions in a single terminal, where containers, but also conventional general cargo or other packaged products, can be handled.

D) *Ro-Ro terminals.* Here cargo is transferred within a roll on–roll off system, with loading and unloading of cargo by horizontally moving lorries, forklifts, tractors, and so on.

E) *Bulk cargo terminals.* At these terminals, liquid or dry bulk cargo without packaging is handled. Usually, pumping machinery with suitable piping or grab cranes is used at these terminals.

Extreme weather conditions do not affect each terminal in the same way. Winds that affect passenger ships, ferries and recreational boats are not considered prohibitive to container or larger ships; rain that affects dry bulk cargo (especially on an open deck ship) does not affect containers. Excessive heat and especially humidity does not affect Ro-Ro shipping cargo but does affect container cargo.

The productivity of a port is the measure of its ability to move cargo through it within a unit of time under actual conditions (Figure 6). It is known that cargoes undergo various stages of handling while in port. For example, imported goods undergo the following handling procedures:

- discharging while a vessel is berthed
- transport to storage area and stowage
- removal from storage and transport to area of transshipment or to means of overland transport
- loading onto means of overland transport
- departure from the port.

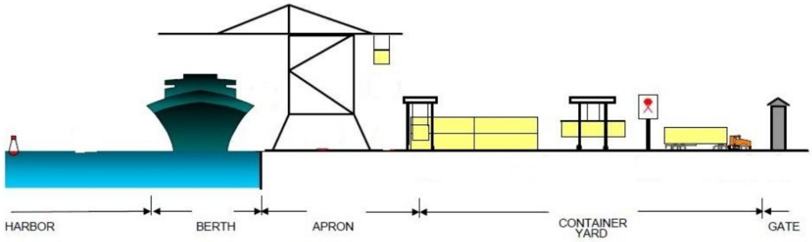
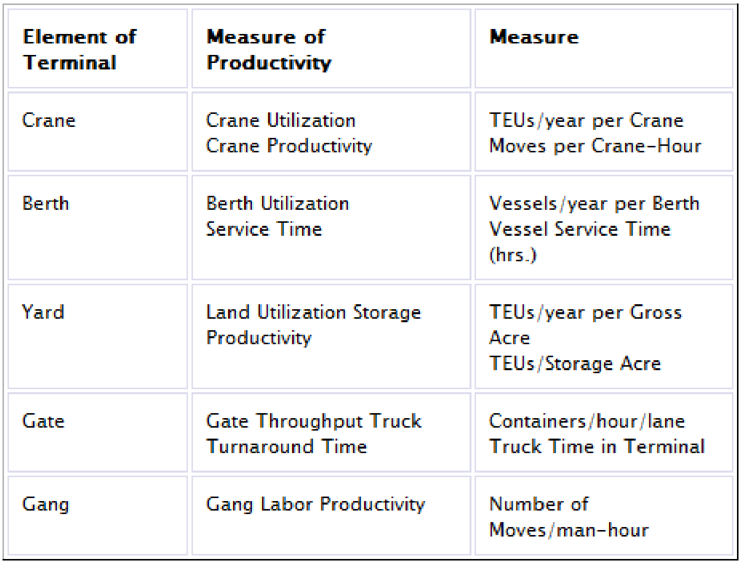


Figure 6. Stages of cargo processing within a port.

Obviously, the total productivity of a port is determined by the lowest partial productivity of each link in the cargo handling chain. However, the most typical pairs of consecutive cargo handling legs in port cargo handling procedures are *dock loading and unloading* (transport from quay to storage area, or vice versa) and *transport from storage area to means of overland transport: (*flow of means of transport to and from inland areas). The conditions prevailing at the port at any given moment, such as weather conditions, human resources, and condition of machinery, affect the productivity of these procedures considerably.

In order to measure these, the basic components must be examined. In the following table (Table 10) the most basic components of dock loading and unloading and transport from storage areas to means of overland transport are presented, along with their units of speed:

Table 10. Port measures of efficiency. (Source: Rankine, 2003)



Element of Terminal	**Measure of Productivity**	**Measure**
Crane	Crane Utilization Crane Productivity	TEUs/year per Crane Moves per Crane-Hour
Berth	Berth Utilization Service Time	Vessels/year per Berth Vessel Service Time (hrs.)
Yard	Land Utilization Storage Productivity	TEUs/year per Gross Acre TEUs/Storage Acre
Gate	Gate Throughput Truck Turnaround Time	Containers/hour/lane Truck Time in Terminal
Gang	Gang Labor Productivity	Number of Moves/man-hour

Another factor one must consider is what types of extreme weather events are common for a particular port. Northern European ports, for instance, are more susceptible to cold waves, ice, fog and strong winds, while southern European ports may face more problems from wind, heat waves and heavy rain (southern European ports, especially Mediterranean ports are more heavily loaded with tourists).

Of course, the most important aspect in order to evaluate the cost of extreme weather in loading/unloading cargo is to define exactly how weather affects the whole procedure of loading and unloading. As previously mentioned, this depends mainly on the type of cargo and ship. It is a very broad subject; however given the rise of container shipping one should definitely look into container transport. Despite the fact that maritime shipping is dominated by bulk cargo, which roughly accounted for 69.6% of all the ton-miles shipped in 2005, the share of break-bulk cargo is increasing steadily, mainly because of containerization (Figure 7). As of 2009 approximately 90% of non-bulk cargo worldwide is moved by containers stacked on transport ships. Between 1990 and 2008, container traffic has grown from 28.7 million TEU to 152.0 million TEU, an increase of about 430%. This corresponds to an average annual compound growth of 9.5%. During the same period, container throughput went from 88 million to 530 million TEU, an increase of 500%, equivalent to an average annual compound growth of 10.5%. In 2009, almost one quarter of the world's dry cargo was shipped by container, an estimated 125 million TEU or 1.19 billion metric tons worth of cargo (Rodrigue et al., 2009)

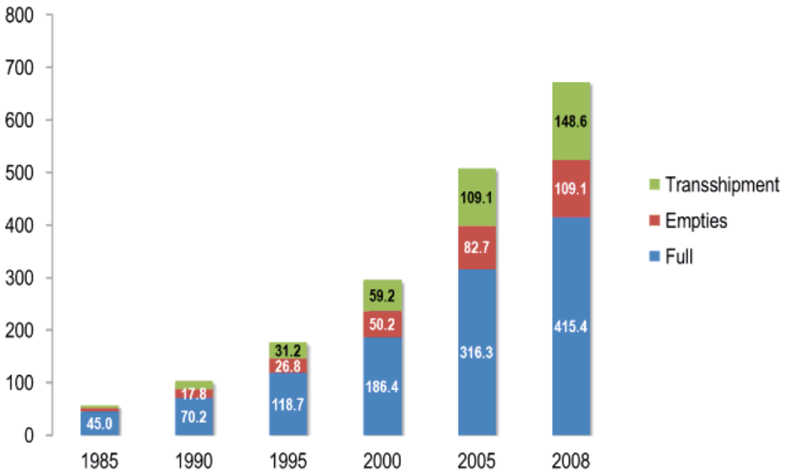


Figure 7. Growth of containers handled by ports from 1985 to 2008.

In general, containers are considered both as means of transport as well as storage units, a great advantage over bulk cargo which is more exposed to the elements. In spite of that, containers remain somewhat susceptible to weather elements: Rain in the long term will rust a container, reducing its durability, exposure to heat will affect both a refrigerated container and a regular one because will produce humidity if the containerization process was not made according to standard procedure.

However, the most important aspect one must examine considering extreme weather events and port productivity remains the human factor. Human operators pervade all aspects of cargo processing within a port and Health and safety procedures and regulations are meant to be enforced and followed in order to allow the maximum port performance with the minimum risk involved. Each country and port has its own set of regulations depending on the type of the port, the prevailing weather conditions, special geographical characteristics, etc.

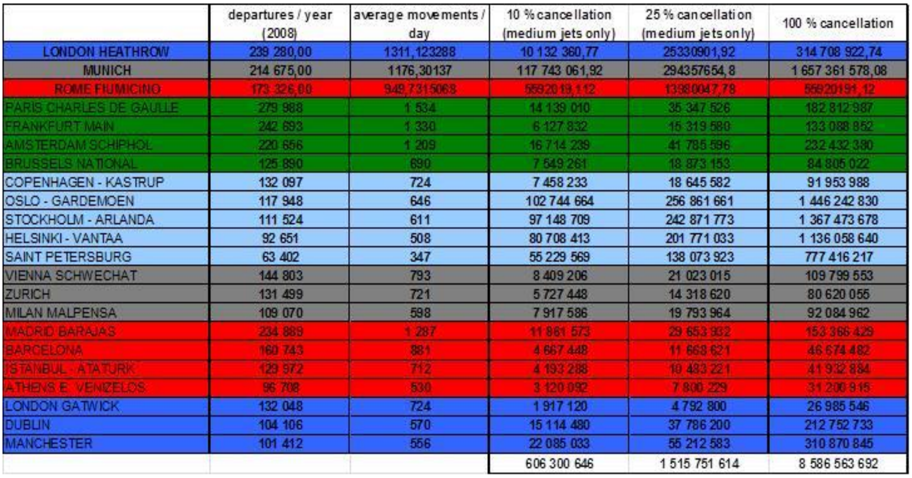
2.4.2 Airline operator costs

One of the aspects of the airline services is that the airlines bear costs of delays and cancellations of flights. Total costs of cancellations to the industry depend on the amount of flights cancelled as percentage of total flights. The following table shows a summary of 10%, 25% and 100% across selected airports in Europe. The case of 100% cancellations realised in 2010, when the volcanic ash cloud of Iceland resulted in closure of the European airspace.

The figures reported in Table 11 were calculated as follows. The total volume of flights annually from the airports (departures and movements) was used as a starting point to calculate average movements per day. Percentage share of heavy jets and medium jets was estimated based on in-depth study of movements in three airports (London Heathrow, Munich and Rome Fiumicino). This was necessary to estimate the costs for two distinguished types of planes (for European and intercontinental flights), which also have different values for cancelled flights (75 000 euro for heavy jets and 16 000 euro for medium jets). However, to take into consideration the fact that airlines usually respond to impacts of extreme weather phenomena by cancelling medium jets first, the first two estimates presented only show impact of medium jet cancellations. The 100 per cent cancellation represents a scenario where all flights independent of plane type were cancelled such as the case of volcanic ash cloud.

The way the figures are presented reflects the actual number of bad weather days in 2008 at the airports. The types of weather phenomena included in the analyses are fog, wind gusts and cold spells. For each airport the most dominant extreme weather phenomena was chosen (to avoid possible of double-counting days with more than one weather phenomena occurring). Thus, the figures below represent the scenario for each airport of what would have been the total annual cost at these airports at different cancellation rates given the number of days with bad weather. The final column shows an estimate of the impact of one day closure of European airports.

Table 11. Airline operator costs of cancelled flights.



	departures / year (2008)	average movements / day	10 % cancellation (medium jets only)	25 % cancellation (medium jets only)	100 % cancellation
LONDON HEATHROW	239 280,00	1311,123288	10 132 360,77	25330901,92	314 708 922,74
MUNICH	214 675,00	1176,30137	117 743 061,92	294357654,8	1 657 361 578,08
ROME FIUMICINO	173 326,00	949,7315068	5592019,112	13980047,78	55920191,12
PARIS CHARLES DE GAULLE	279 988	1 534	14 139 010	35 347 526	182 812 987
FRANKFURT MAIN	242 693	1 330	6 127 832	15 319 580	133 088 852
AMSTERDAM SCHIPHOL	220 656	1 209	16 714 239	41 785 596	232 432 380
BRUSSELS NATIONAL	125 890	690	7 549 261	18 873 153	84 805 022
COPENHAGEN - KASTRUP	132 097	724	7 458 233	18 645 582	91 953 988
OSLO - GARDEMOEN	117 948	646	102 744 664	256 861 661	1 446 242 830
STOCKHOLM - ARLANDA	111 524	611	97 148 709	242 871 773	1 367 473 678
HELSINKI - VANTAA	92 651	508	80 708 413	201 771 033	1 136 058 640
SAINT PETERSBURG	63 402	347	55 229 569	138 073 923	777 416 217
VIENNA SCHWECHAT	144 803	793	8 409 206	21 023 015	109 799 553
ZURICH	131 499	721	5 727 448	14 318 620	80 620 055
MILAN MALPENSA	109 070	598	7 917 586	19 793 964	92 084 962
MADRID BARAJAS	234 889	1 287	11 861 573	29 653 932	153 366 429
BARCELONA	160 743	881	4 667 448	11 668 621	46 674 482
ISTANBUL - ATATURK	129 972	712	4 193 288	10 483 221	41 932 884
ATHENS E. VENIZELOS	96 708	530	3 120 092	7 800 229	31 200 915
LONDON GATWICK	132 048	724	1 917 120	4 792 800	26 985 546
DUBLIN	104 106	570	15 114 480	37 786 200	212 752 733
MANCHESTER	101 412	556	22 085 033	55 212 583	310 870 845
			606 300 646	1 515 751 614	8 586 563 692

colours depict climate zones; red = Mediterranean, blue = Maritime, grey = Temperate Central, pale blue = Northern

What the results show is that cancellations of flights become a serious business factor for airlines. In real life this has resulted in efforts to avoid cancellations and to shift the burden to passengers through delayed flights. The fact that a one-day closure of airports can result in a significant 435 million euro cost for the airlines in

European level is a fact that cannot be overlooked, neither from the industry's nor the societal view. Prolonged closures can lead to a financial crisis amongst the viable operators, thus leading to more future problems for the industry.

The figures above should be treated with caution as the true cancellation rate is not known and may not be uniform across airports. However, what is clearly shown is that the relationship between extreme weather and the resulting cancellation flights is a headache for the airline industry. Efforts to curb these negative impacts are most likely needed and can result in new thinking on the design of new runways and airport facilities.

Regarding the coverage of the aviation industry data, the selected airports cover 88 per cent of daily flight volumes in Europe. As the rest of the airports are operating with less flights relative to their capacity the result can be considered as the lower level boundary estimate. The closest estimate for full impact is between the coverage of the sample and 100% estimated based on the sample, which would already be considered an upper boundary. The same applies to other aviation results.

2.4.3 Freight operators' and shippers' costs

Three notable studies give estimates for value of delay time and for our purpose from different parts of Europe, are carried out in different countries and come from chronologically different period.

Table 12. The comparison of three studies on values of time in freight and logistics. (Ludvigsen et al. 2012)

Study, year	**Country**	**Mode**	**Value of time**	**Unit**	**Notes**
Fowkes, 2004	UK	Road	107	pence / minute / vehicle	Based on the whole sample (N=40) with different actors who had varying delay time value preferences; **value of delay**
De Jong et al., 2004	Netherlands	Containerised cargo	42	€ / shipment / h	Based on the values stated and revealed by shippers; value of **transport time**
		Road	38	€ / shipment / h	
			5.28	€ / tonne / h	
		Rail	918	€ / shipment / h	
			0.96	€ / tonne / h	
		IWT	74	€ / shipment / h	
			0.046	€ / tonne / h	
		Short and deep sea	73	€ / shipment / h	
			0.016	€ / tonne / h	
		Air	7 935	€ / shipment / h	
			132	€ / tonne / h	
Halse et al., 2010	Norway	Road	13.4	€ / tonne / h	Value of **delay** for shippers
			48.4		Value of **delay** for own account hauliers
			1.96		Value of **time** for shippers
			11.8		Value of **time** for own account hauliers

It is noteworthy that the most recent study gives lower values for time for shippers whilst having a sample of at least as high-price-level country as the former studies and with a six year difference lowering the real value of money.

The figures received from the Norwegian study are the most recent and somewhat lower than from the earlier studies. Hence, applying those would probably keep the results on the safer side and there would be no need to adjust for the inflation to be considered up-to-date (2012)[2], particularly as the indices do not necessarily reflect equally well the market context in different countries, which is volatile in itself, and as they might not capture transport markets' idiosyncratic features. The Dutch study we could use to adjust for the modal differences since it was the only one of the three that covered all modes under research. The relative ratios for all modes are in the below table (road, shippers = 1.00) as well as the real cost estimates using the Norwegian values and adjusted values when taking into account the price level difference between Norway and European Union member states (EU27=100.0, NO=147.3 in 2012; Eurostat).

Table 13. Relative, real and adjusted cost estimates for values of time and delay. (Ludvigsen et al. 2012)

Mode		**Relative cost estimates, unit / tonne / h**		**Real cost estimates, € / tonne / h**		**Price level adjusted costs for EU27, € / tonne / h**	
		Shippers'	Hauliers'	Shippers'	Hauliers'	**Shippers'**	**Hauliers'**
Road	Time	**1.00**	6.02	1.96	11.8	**1.33**	**8.01**
	Delay	6.84	24.7	13.4	48.4	**9.10**	**32.8**
Rail	Time	0.182	x	0.357	x	**0.242**	**x**
	Delay	1.24	x	2.43	x	**1.65**	**x**
IWT	Time	0.0087	x	0.017	x	**0.012**	**x**
	Delay	0.059	x	0.116	x	**0.079**	**x**
Short sea	Time	0.0030	x	0.0059	x	**0.0040**	**x**
	Delay	0.021	x	0.041	x	**0.028**	**x**
Airborne	Time	25.0	x	49.0	x	**33.3**	**x**
	Delay	171	x	335	x	**227**	**x**

The rightmost values can be used for EU27 proxies when assessing European shippers' costs for freight delivery delays.

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[2] Two years' difference is insignificant thinking of the inflation adjustment for two good reasons. First, all other assumptions' error margins clearly outweigh two years' inflation adjustment. Secondly, the inflation in the euro-zone has been practically non-existing for the last couple of years because of the financial distress caused by the debt crisis.

3. Pricing decisions for EWENT

3.1 Purchasing power adjustment

The very important part of the analyses is the division of Europe into several climatic zones. These zones also have (in some cases overlapping) several Member States or neighbouring countries in each of them. This means that it is possible to estimate for each country – even when no official figures are available – purchasing power parity (PPP) adjusted value of travel time and accidents, from defined representative figures. For these purposes we use comparative price levels, measured as the scaled levels of final consumption in each country as the adjusting factor. The grouping by regions also allows for calculation of regional representative estimates, taking into consideration the population in each country. This is a valid method in particular for accident costs, as we also have national level data available from each country.

Based on the reported accident cost values, we propose the following figures to be used as normative, to be adjusted for each country according to PPP:

- fatality: 1 000 000 euro
- severe injury: 250 000 euro
- slight injury: 40 000 euro.

These figures represent averages from the data collected from various countries and should allow for comparison, when adjusted to various EU Member States.

For the actual PPP adjustments needed in calculations in other deliverables of WP4, we use the Eurostat figures for comparative price levels of final consumption by private households, reported in (Table 14).

We propose the following EU averages of travel time to be used for transport modes other than aviation, where the values have been agreed on during a unified framework:

- Commuting travel: 10 euro/hour
- Leisure travel: 6 euro/hour
- Work-related travel: 20 euro/hour.

Again, these figures can be adjusted to individual Member States for more detailed analyses.

For freight, the pricing decisions will be introduced in later sections of the report.

Table 14. Comparative price levels of final consumption by private households including indirect taxes in 2010 (EU-27=100). (Source: Eurostat)

Year 2010		**Fatality**	**Severe injury**	**Slight injury**
European Union 27	100	1 000 000	250 000	40 000
Belgium	111.6	1 116 000	279 000	44 640
Bulgaria	50.5	505 000	126 250	20 200
Czech Republic	72.0	720 000	180 000	28 800
Denmark	142.5	1 425 000	356 250	57 000
Germany	104.2	1 042 000	260 500	41 680
Estonia	75.1	751 000	187 750	30 040
Ireland	118.2	1 182 000	295 500	47 280
Greece	95.5	955 000	238 750	38 200
Spain	96.7	967 000	241 750	38 680
France	111.8	1 118 000	279 500	44 720
Italy	103.6	1 036 000	259 000	41 440
Cyprus	89.3	893 000	223 250	35 720
Latvia	69.3	693 000	173 250	27 720
Lithuania	63.5	635 000	158 750	25 400
Luxembourg	119.9	1 199 000	299 750	47 960
Hungary	65.5	655 000	163 750	26 200
Malta	78.9	789 000	197 250	31 560
Netherlands	106.1	1 061 000	265 250	42 440
Austria	107.1	1 071 000	267 750	42 840
Poland	62.6	626 000	156 500	25 040
Portugal	87.6	876 000	219 000	35 040
Romania	58.6	586 000	146 500	23 440
Slovenia	84.0	840 000	210 000	33 600
Slovakia	71.2	712 000	178 000	28 480
Finland	122.9	1 229 000	307 250	49 160
Sweden	119.8	1 198 000	299 500	47 920
United Kingdom	100.3	1 003 000	250 750	40 120
Liechtenstein	n.a.	n.a.	n.a.	n.a.
Norway	147.3	1 473 000	368 250	58 920
Switzerland	148.0	1 480 000	370 000	59 200
Montenegro	58.7	587 000	146 750	23 480
Croatia	74.1	741 000	185 250	29 640
Former Yugoslav Republic of Macedonia	44.3	443 000	110 750	17 720
Turkey	73.0	730 000	182 500	29 200

3.2 Accident costs

3.2.1 Current accidents at the European level

The status and volume of accidents for each transport mode was reported in Mühlhausen et al. (2011). This section only presents a summary of the results from the earlier report. For inland waterways, no comprehensive data were available on accidents at the European level (the volume of accidents is known from the Eurostat transport statistics, but not the number of fatalities or injuries), so an estimation was made using the relationship from other transport modes between number of accidents and related injuries. The accident data is reported in Table 15.

In other transport modes (barring road and rail) the amount of accidents on an annual level is so small that any major accident can lead to considerable changes in accident amounts. In marine/short-sea shipping the accident volume is also directly related to the volume of shipping activity; in the statistics the year 2009 total number of fatalities was 52, when in 2007 and 2008 annual fatalities were 82 for both years. In 2009 the freight volumes declined due to the financial crisis and global recession.

Since the European Union accident statistics from Eurostat do not specify the cause of the accidents or give any details of the conditions in which accidents have taken place, the accidents resulting from extreme weather cannot be disintegrated by the cause. Such an exercise could be possible using the data from those rare countries where more detailed accidents data is available, but this would not create figures that are credible. As we know the main causes of road accidents (as defined in Deliverable 1 of the project), it is possible out of the accident volumes (country by country) to identify the most likely causes. However, that is beyond the monetisation done in this deliverable as the focus in on providing a European estimate of the total costs.

Table 15. Fatalities and severe injuries across transport modes for EU-25, accession countries and Switzerland. (Sources: European road accidents statistics (Eurostat), Maritime accident review, Railway accidents statistics as specified in Mühlhausen et al., 2011; PLANCO Consulting GmbH, 2007)

Transport mode	**Fatalities**	**Severe injuries**	**All injuries**
Road[1]	49 004	376 251	1 980 269
Rail[2]	1 498	1 350	N/A
Inland waterways[3]	7	17	266
Marine/short-sea shipping[4]	52 / 61	360	1 600
Aviation[5]	0	N/A	N/A
[1]2007; [2]2008; [3]Based on calculations from IWW data, Excluding Bulgaria and Romania; [4]2009/2010; [5]2010			

For the purpose of determining the portion of accidents caused by weather in road transport, we used the detailed Finnish accident data from 2006 to 2010. The average number of fatalities and injuries from weather-related accidents was around 20 per cent over the period. This may represent a higher end estimate in terms of the European average, as weather conditions in Finland, particularly in the winter time, are tougher than in most parts of Europe. On the other hand, since the conditions are more familiar to road users in Finland, preparedness to encounter them is also most likely above the average. The data does not also indicate what portion of the accidents linked with weather conditions can be classified taken place under conditions that exceed the threshold values for severe occurrence. We have used an estimate of half (10%) of the accidents being a result of extreme weather. This is also in line with findings from the other research projects as for instance those from Norway reported in Mühlhausen et al. (2011). For the sensitivity analyses, additional calculations using 5% and 15% per accident ratios were also carried out.

For the other transport modes, the probabilities from road transport appear too high. There is no similar data available for the other modes as is for the road transport, so expert estimates were provided by VTT and FMI staff members. For marine/short-sea shipping, the small number of accidents suggests that the probabilities could be half of those observed in the road transport.

The share of weather-related accidents seems also lower in inland waterways, where the study results reported in work package 3 indicate that only 10% of the accidents in inland waterways are related to poor weather. In marine / short-sea shipping this percentage is most likely higher, as extreme weather events contribute more to the accidents in sea transportation. For rail, similarly, we applied the lower level estimate of 10%, with sensitivity analysis of 5% and 15% respectively.

Aviation was left out of the analyses, as the amount of accidents in the industry was small and was not considered relevant for calculations. For instance, in 2010 no fatalities took place in the entire European airlines passenger transport.

For pricing of the fatalities and injuries, we use the European level round figure estimates. The figures include EU-25, Switzerland and the Accession countries. The value of life is estimated at 1 million € and the severe accident at 250 000 €. Additional costs of slight injuries were estimated at 40 000 € accident. The estimates and sensitivity analyses are shown in Table 16 below.

Table 16. European level total accident costs resulting from extreme weather (€).

Transport mode	**Road* 2008**	**Rail 2009**	**IWT 2005**	**Marine / short-sea 2009–10**
Baseline scenario				
Percentage of accidents resulting from extreme weather	10	5	10**	5
Fatalities	4 900 400 000	74 900 000	800 000	2 600 000
Other injuries	15 824 587 000	28 390 000	1 600 000	7 700 000
Total	20 724 987 000	103 290 000	2 400 000	10 300 000
Total European level estimate 20 840 977 000 €				
Sensitivity analysis				
Upper level estimate: Percentage of accidents resulting from extreme weather	15	7.5	15	7.5
Total 31 261 465 000 €				
Lower level estimate: Percentage of accidents resulting from extreme weather	5	2.5	5	2.5
Total 10 472 133 000 €				
*The number of fatalities and injured in the calculations excludes the Russian Federation ** Rounded figure (11%, Lammer, D. 2007. Machbarkeit eines Kollisionsvermeidungssystems in der Binnenschiff-fahrt. Fach-Hochschule Wiener Neustadt. In German)				

The total volume of accident costs at the European level is estimated at 20.8 billion euro, and the subsequent sensitivity analyses give also lower and upper level estimates of what the possible changes in assumptions can bring about. The figures are massive, and the major contributing factor is the road transport with its large proportion of accidents and their resulting fatalities and injured persons. Given that the accidents are significantly smaller in other transport modes with less weather-related accidents, the result is hardly surprising.

As there are great variations between countries in terms of the number of accidents, we have extended the analyses to cover the 5 climate regions in the following section of the report. The purpose of this is to provide an understanding of the difficulties associated with extreme weather phenomena across Europe.

3.2.2 Estimates of current accidents at the various climate zones

Europe is divided into climate zones (EWENT D1, Leviäkangas et al., 2011). A further division was carried out in work package 2 of the project, as the climate zones were further classified according to their features. The division into six different climate zones is as follows (Figure 8)

- Northern European (sub-arctic) region: NE
- Maritime (Oceanic) region: O
- Mediterranean region: M
- Temperate Central European region: Tc
- Temperate Eastern European region: Te
- Alpine (Mountainous) region: A.

This regional division will be used in order to provide European estimates of regional impacts of accidents. Calculations are carried out for road transport only, as this represents the largest amount of accidents across transport modes. It is also the transport mode where the best data availability of country level accidents is provided at detailed level (from Eurostat).

Figure 8. Classification of climatologically similar European regions. (Source: Vajda et al., 2011)

For calculation purposes, most countries (in principle) fit into one of the climate zones, but some countries pose more of a challenge. Table 17 below presents the classification adopted in Vajda et al. (2011). A particular case is Italy which, by the geographical zone borders, is part of both Mediterranean and Alpine regions. Therefore, in the analyses that follow below, Italy is divided into two regions with equal shares of accidents for each. There are other possible cases of geographically large countries (in particular France and Hungary) where a similar approach would have been possible due to them being located in more than one climate region, but for the sake of simplicity they remain in one region each.

Table 17. European countries classified by climatological region.

COUNTRY	**CLIMATOLOGICAL REGION**					
	NE	*O*	*Tc*	*Te*	*M*	*A*
Austria			*			*̲
Belgium		*				
Bulgaria				*		
Cyprus					*	
Czech Republic				*		
Denmark	*̲		*			
Estonia				*		
Finland	*					
France		*̲			*	*
Germany			*̲			*
Greece					*	
Hungary			*			
Ireland		*				
Italy					* (50%)	* (50%)
Latvia				*		
Lichtenstein						*
Lithuania			*			
Luxemburg		*				
Malta					*	
Netherlands		*				
Norway	*̲					*
Poland			*	*̲		
Portugal					*	
Romania				*̲		*
Slovakia			*			*
Slovenia			*̲		*	*
Spain		*̲			*	*
Sweden	*̲					*
Switzerland						*
United Kingdom		*				

Note: For those countries classified into more than one region, the one where they have been assigned in the analysis is shown with underlined asterisk (*̲). For countries denoted with *italics*, no accident data was available.

For those countries, where unit values are available, the calculations utilise the actual official values of statistical life. Where no official values are available, the adjusted figures from European level estimate were used. Table 18 below presents the estimates for each region. From the data it can be seen that there is a clear causality between the population of the countries, their road accidents with fatalities and the associated costs.

Table 18. Regional estimates for fatalities costs of road accidents for various climate zones, mill. €/a.

Climate zone	Total no. of fatalities	Cost (mill. € per year)
Northern European	1 499	277 559
Temperate Central European	8 593	299 962
Temperate Eastern European	13 058	870 176
Alpine	6 704	728 604
Mediterranean	5 490	416 311
Maritime	13 658	1 553 687

The figures in Table 18 are also presented graphically in the Figure 9 below.

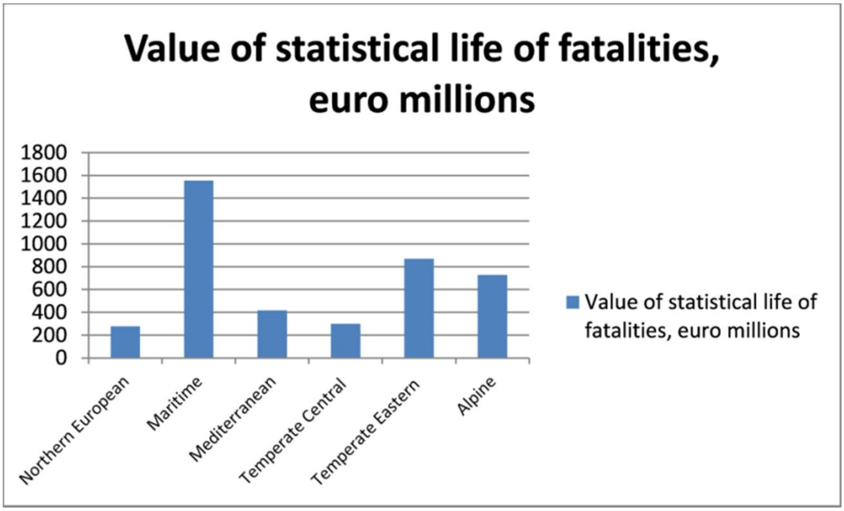


Figure 9. Climate zone estimates of fatalities costs in road transport.

It should be noted that these figures are not comparable to those presented in the previous section, where the European level estimates were calculated using a rough estimate of average values. The figures for fatalities by region are slightly lower than the ones calculated in the European level estimate, as the countries for which official values are available had higher values than the average. Also, the fact that most countries which are using determined statistical values of life have less accidents in terms of their volume makes the case for lower total when calculated by countries, as those countries with no valuations available have larger volumes of accidents (and lower purchasing power than average).

The regional disparities are explained by two major factors: The Maritime region contains countries with large populations and an associated volume of accidents. This results in the largest cost in financial terms. However, the amount of accidents in temperate Eastern Europe is equally large but the associated social cost is just above 50 per cent of the Maritime due to the income disparity between the two regions. The large social cost of Alpine region is, again, a result of the above European average income level, which results in larger social costs, when official accident valuation figures of the countries are used.

3.3 Time costs

3.3.1 Road transport – passenger

For road transport, estimates presented here are based on cities studied. For freight, the impacts are discussed in later sections. As the daily commuting volumes are known for certain major cities, the information can be used to estimate the average change in travel time, and, therefore, the associated cost in terms of time used for commuting. The figures presented here cover only passenger transport.

Methodologically, the fact that travellers are all experiencing similar conditions means that delays will become identical as the speed of traffic slows down equally for all passengers. However, to be able to calculate time costs accruing to passengers, several datasets would be required. When interested in the calculation of value of time savings or costs, data on trip volumes and lengths is needed. Usually a source of such information is commuter/travel surveys, which are conducted in many major cities. Based on the number of days with bad weather and the amount of commuter trips, their length and time spent on the journey, it is indeed possible to present estimates of how extreme weather conditions contribute to social costs in the form of increased travel times.

Part of the challenge for the calculation of exact time costs is data availability as explained. For cities where good data exists, calculations can be carried out. For instance, an example of traffic volumes in the Helsinki metropolitan area can be used to illustrate the calculation process. To begin with, the pattern of commuting travel is shown in Table 19 below. The figures are old, from 1998, but give an illustration of distribution of commuter travel patterns. Using the distribution below, it is possible to analyse the impact of extreme weather on trips, as long as there is some estimate of the impact of weather on speed. It should be noted that the average length of a commuting trip in the Helsinki area was 8.4 kilometres, however, in the calculations below we use the more detailed travel pattern in order to take into consideration the time costs resulting from different distances and average speeds.

Table 19. Travel pattern data of commuter trips in the Helsinki Metropolitan area. (Source: Finnish mobility statistics, 2001)

Trip length	**Share of trips**	**% of total travel**
0–2 km	20 %	2 %
2–5 km	20 %	8 %
5–20 km	56 %	67.5 %
20–50 km	3 %	10.5 %
50–100 km	0.5 %	5 %
100–150 km	0.5 %	7 %

Another factor which needs to be taken into consideration is the daily volume of trips that will enable the calculation of total time costs according to travel patterns. According to Helsinki City travel survey, the daily commuter volume is approximately 560 000 commuters. Using the data from Table 19 and allowing for some variation in estimated speed of travel and impact of weather it is possible to construct a table of impacts as shown in Table 20. The calculations were conducted as follows: For each trip length an average was calculated. This average multiplied by amount trips gives the total kilometres for each category. To be able to calculate the impact of reductions, the average speed for trips was estimated. This is important, as the average speed enables to calculate some sensitivity analyses of the actual impact of extreme weather. For shorter trips, average speeds were lower and for longer trips higher, considering the utilisation of major roads network and taking into consideration the time spent on commuting. It is evident that changing the travel speeds is another variable that can be used in the sensitivity analysis.

Finally, three different alternatives for speed reduction were estimated: 20%, 30% and 40% reduction of average speed. For instance, in the average speed of 80 kilometres per hour these would correspond to speed of 64, 56 or 48 kilometres per hour driving speeds. They may seem low, but it needs to be taken into consideration that factors such as poor visibility, collisions and insufficient equipment (windshield wipers, poor tires etc.) can also contribute to the reduction in the speed.

As shown in Table 20, the daily costs of delays over the commuting traffic are several hundreds of thousands of euro on daily basis depending on which estimate of speed reduction is applied. As in Helsinki at present the amount of extreme weather days is only a few, resulting from either heavy rain, blizzards or snow, combined with icy road conditions. Thus, for a city like Helsinki the annual costs can be already significant as there are many days when such costs can be realised.

Table 20. Estimated time costs as a consequence of extreme weather in Helsinki, daily costs in euro.

Trip length	**Total amount of trips**	**Total kms as average of trip length**	**Estimated average speed of travel (km/h)***	**Reduction of 20% of average speed, time costs (€)**	**Reduction of 30% of average speed, time costs (€)**	**Reduction of 40% of average speed, time costs (€)**
0–2 km	112 000	112 000	10	22 400	33 600	44 688
2–5 km	112 000	392 000	20	39 200	58 800	78 204
5–20 km	313 600	3 920 000	40	196 000	294 000	391 020
20–50 km	16 800	588 000	60	19 600	29 400	39 102
50–100 km	2 800	210 000	80	5 250	7 875	10 473
100–150 km	2 800	350 000	100	7 000	10 500	13 965
Total costs				*289 450*	*434 175*	*577 453*

*It is assumed that the longer the trip, the higher the average speed due to use of regional roads or motorways. These estimates are in line with the data published by Finnish National Road Authority (Ylönen, 2011).

One factor that has been found in the international research on impact of weather on road transport is the traffic intensity impact. This means that road users are likely to respond to anticipated bad weather conditions by reducing their travel. However, this may not be possible in the case of unexpected adverse weather conditions or in the case of commuting travel, when the persons are expected to travel to and from a work place according to terms of employment contract.

It is natural that different weather phenomena will impact road users with different total impacts; in this respect having a scale of options for impact assessment available for analyses is very useful. It should be also noted that the accidents discussed earlier in this deliverable happen in connection with the same travel patterns for which we are calculating the delays. In fact, often an accident will result in longer delays as the traffic is further slowed down by blockages of roads due to accidents.

To take the analyses further, the daily delay costs need to be contrasted with weather data. As the winters 2009–2010 and 2010–2011 were extremely cold, the data from 2008–2011 extreme weather phenomena were analysed in greater detail. By frequency of events, the strong winds (1st threshold, 17m/s) and heat waves dominated the extreme weather events in Helsinki region. These are also the phenomena that do not have a significant impact on delays in road or rail transport. So the analyses presented below will focus on strong winds, 2nd threshold (25 m/s), heavy snowfall, cold spells and heavy precipitation.

What is interesting to note is that co-existence of two or more extreme weather phenomena is really rare but, naturally, makes the conditions even more challenging. During the span of 4 years, simultaneous occurrence happened only on 5 days. Of these the most interesting is August 8, 2010, when heat waves together with strong winds and thunderstorm created a difficult driving weather for the summer period. This resulted in difficult driving conditions and dropped speeds by nearly 50 per cent even in the motorways due to poor visibility and slippery road conditions.

Data shows that in 2008 there were 5 days that were considered to create problems to traffic, 3 days in 2009, 15 days in 2010 and 11 days in 2011. This makes it a total of 32 days during which extreme weather has resulted in conditions that could be considered to create delays in transport. Taking into consideration that, on 5 days, two events took place simultaneously, out of which one day had occurrence of two of the phenomena assessed here, the total number is 31 days of weather interruptions.

The breakdown by phenomena is:

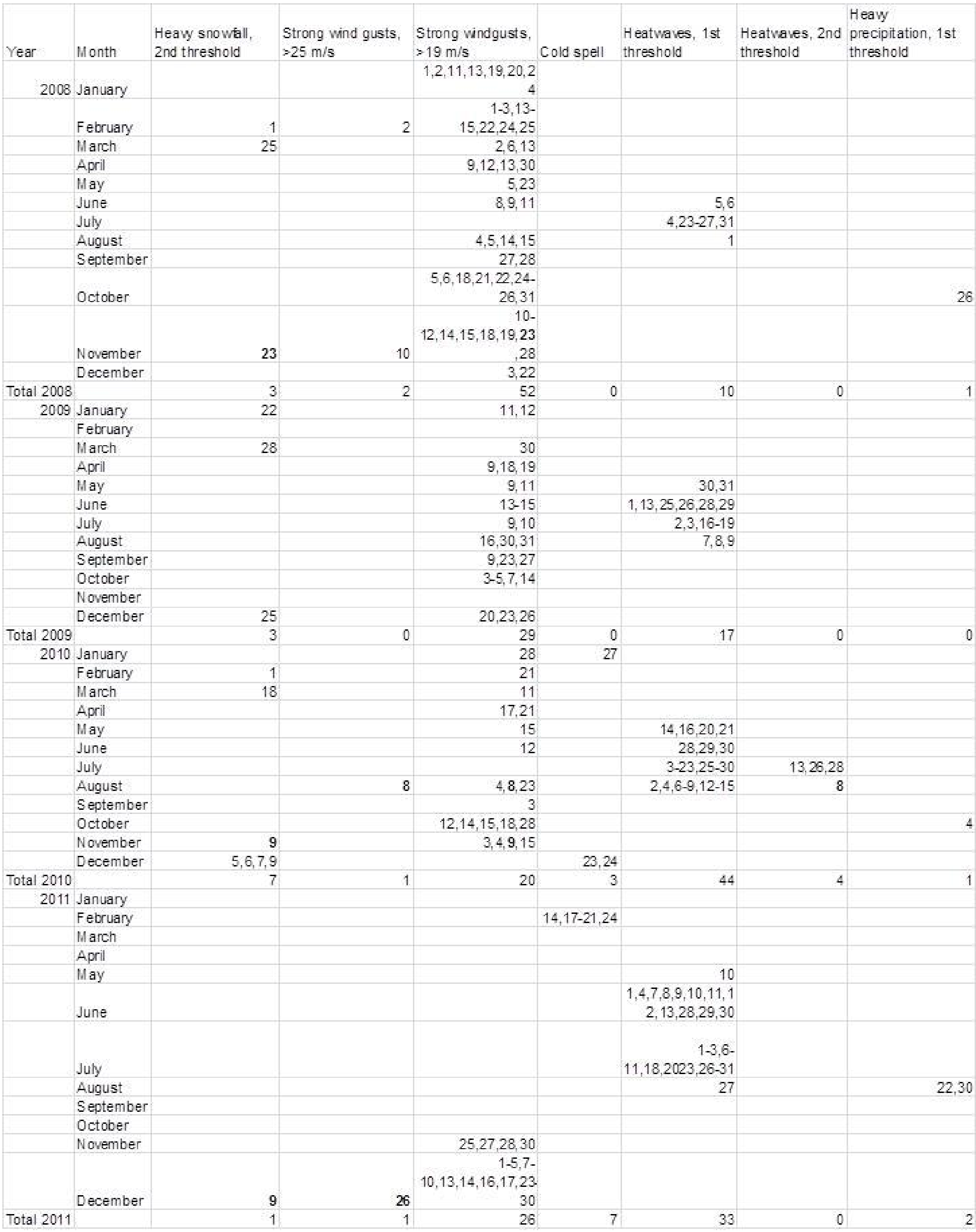
- Heavy snowfall (≥ 10 cm/24 h) 14 days
- Heavy wind gusts, (≥ 25 m/s) 4 days
- Cold spells (≤ -20 °C) 10 days
- Heavy precipitation (≥ 30 mm) 4 days.

By season the breakdown is:

- Summer 2 (including 2 events occurring simultaneously)
- Autumn 5
- Winter 21
- Spring 3.

Table 21 below shows the daily occurrence of the extreme weather phenomena in Helsinki region for the years 2008–2011. Calculating on the basis of the 31 days of extreme weather the delay costs will yield between 9 and 17.9 million euro of time losses based on the sensitivity analysis, averaging between 2.2 and 4.5 million euro annually. Since this is only the amount for the Helsinki region, it is understandable that similar problems in larger cities (for instance, London and snow) would yield considerable higher time costs due to greater traffic volumes affected by the weather. On the other hand, snow weather is less probable in London than Helsinki, so the ultimate expected losses are a function of impact and probability.

Table 21. Extreme weather phenomena reported in Helsinki region, 2008 – 2011. (Source: FMI database)



Year	Month	Heavy snowfall, 2nd threshold	Strong wind gusts, >25 m/s	Strong windgusts, >19 m/s	Cold spell	Heatwaves, 1st threshold	Heatwaves, 2nd threshold	Heavy precipitation, 1st threshold
2008	January			1,2,11,13,19,20,24				
	February	1	2	1-3,13-15,22,24,25				
	March	25		2,6,13				
	April			9,12,13,30				
	May			5,23				
	June			8,9,11		5,6		
	July					4,23-27,31		
	August			4,5,14,15		1		
	September			27,28				
	October			5,6,18,21,22,24-26,31				26
	November	**23**	10	10-12,14,15,18,19,**23**,28				
	December			3,22				
Total 2008		3	2	52	0	10	0	1
2009	January	22		11,12				
	February							
	March	28		30				
	April			9,18,19				
	May			9,11		30,31		
	June			13-15		1,13,25,26,28,29		
	July			9,10		2,3,16-19		
	August			16,30,31		7,8,9		
	September			9,23,27				
	October			3-5,7,14				
	November							
	December	25		20,23,26				
Total 2009		3	0	29	0	17	0	0
2010	January			28	27			
	February	1		21				
	March	18		11				
	April			17,21				
	May			15		14,16,20,21		
	June			12		28,29,30		
	July					3-23,25-30	13,26,28	
	August		8	4,8,23		2,4,6-9,12-15	8	
	September			3				
	October			12,14,15,18,28				4
	November	**9**		3,4,9,15				
	December	5,6,7,9			23,24			
Total 2010		7	1	20	3	44	4	1
2011	January							
	February				14,17-21,24			
	March							
	April							
	May					10		
	June					1,4,7,8,9,10,11,12,13,28,29,30		
	July					1-3,6-11,18,2023,26-31		
	August					27		22,30
	September							
	October							
	November			25,27,28,30				
	December	**9**	**26**	1-5,7-10,13,14,16,17,23-30				
Total 2011		1	1	26	7	33	0	2

As the example shows, we can distinguish data providing, between seasonal, weather-phenomena type and whether the phenomena will have impact on the particular transport mode. In the following section the impact on rail commuting passengers will be analysed.

The results from Helsinki MA commuting can be used to analyse the respective costs in other European major cities, as classified in work package 3. The figures presented in Table 22 below were obtained by using the 2–4 euro/resident in Helsinki MA as an indicative figure of costs of delays per resident in the major cities. As can be seen, on annual basis the costs of delays total a significant loss in value of time. The figures exclude other cities in the regions, thus suggesting a lower boundary estimate of the total costs.

Table 22. Estimated annual time costs of extreme weather borne by road commuter traffic in major European cities.

	Major cities	**Population**	**Estimated costs, million € / year, ppp-adjusted**
Scandinavian (North European)	SAINT PETERSBURG	**4 661 219**	**9.3 – 18.6**
	STOCKHOLM	**1 252 020**	**2.4 – 4.8**
	COPENHAGEN	**1 189 231**	**2.8 – 5.5**
	HELSINKI MA	**1 029 773**	**2.0 – 4.0**
	OSLO	**907 288**	**2.2 – 4.3**
Temperate (Eastern & Central)	BERLIN	**3 440 441**	**5.8. – 11.7**
	PARIS	**2 203 817**	**4.0 – 8.0**
	HAMBURG	**1 773 218**	**3.0 – 6.0**
	WARSAW	**1 711 466**	**1.7 – 3.5**
	COLOGNE	**1 000 298**	**1.7 – 3.4**
	BUDAPEST	**1 721 556**	**1.8 – 3.7**
Alpine	VIENNA	**1 712 903**	**3.0 – 6.0**
	MILAN	**1 311 741**	**2.2 – 4.4**
	MUNICH	**1 356 594**	**2.3 – 4.6**
	TURIN	**909 960**	**1.5 – 3.1**
Mediterranean	MADRID	**3 255 944**	**5.1 – 10.2**
	ROME	**2 756 502**	**4.6 – 9.3**
	BUCHAREST	**1 944 367**	**1.9 – 3.7**
	BELGRAD	**1 594 000**	**1.9 – 3.8**
	BARCELONA	**1 621 537**	**2.6 – 5.1**
Maritime (Oceanic)	LONDON	**7 556 900**	**12.3 – 24.7**
	BIRMINGHAM	**1 016 800**	**1.7 – 3.3**
	LEEDS	**770 800**	**1.3 – 2.5**
	GLASGOW	**581 900**	**0.9 – 1.9**
	SHEFFIELD	**534 500**	**0.9 – 1.7**
Total		**23 108 343**	**67.7 – 135.8**

3.3.2 Rail – passenger

For rail, the calculations are analogical to those of road transport in the commuting traffic. Using the previous example from Helsinki Metropolitan Area, where, according to commuting survey statistics (Helsingin kaupunki, Kaupunkisuunnitteluvirasto, 2009), 5% of daily commuters use train for their travel. Thus, the total volume of commuters using rail is approximately 28 000 commuters on daily basis. If similar pattern of travel behaviour is assumed for rail users, the estimated delays can be presented as shown in Table 23 below. Similarly to road users, we assume that the delays due to adverse weather conditions result in lower average speeds, which mean that for some passengers the impact can be realised in full greater than the average speed indicates whereas for others the impact could be lesser or insignificant. This can typically happen during a day when the conditions gradually improve and measures are taken to address the weather challenge.

For the speed of travel, analogical to road transport, estimates of average speed were used to illustrate the impact of delay as a consequence of weather and the associated worsening conditions on track.

Table 23. Rail transport time costs in Helsinki region. (Source: City of Helsinki, 2009)

Trip length	**Total no. of trips**	**Total kms as average of trip lenght**	**Estimated average speed of travel kms/h**	**Reduction of 20% of average speed, time costs**	**Reduction of 30% of average speed, time costs**	**Reduction of 40% of average speed, time costs**
0–2 km	5 600	5 600	10	1 120	1 680	2 234
2–5 km	5 600	19 600	40	980	1 470	1 955
5–20 km	15 680	196 000	60	6 533	9 800	13 034
20–50 km	840	29 400	80	735	1 102	1 466
50–100 km	140	10 500	100	210	315	419
100–150 km	140	17 500	120	292	438	582
Total costs				*9 870*	*14 805*	*19 691*

As it can be seen from Table 23, the assumptions regarding the average speed of travel are higher for rail than for road transport. This assumption is based on the railway system in Finland, where high speed trains cover greater distances with less stops and greater average speed. However, due to the smaller passenger volume the results show that rail time costs play a smaller role in the calculation of social costs than those of road passenger transport.

Taking the weather data used in the previous section for the road transport, we can see that the total cost of delays for train commuting passengers was between 306 000 euro and 61 000 euro over the period or 76 500–152 000 euro per year on the average.

As in the case of road transport, we can also estimate the costs of delays on rail passengers using the Helsinki data as the benchmark. Similar to the road calculations, the figures presented in Table 24 below show the adjusted figures for major cities in different climate zones. Not surprisingly, due to the lower volume of rail commuters the delay costs are also significantly lower than in the case of road transport. Based on the Helsinki MA data we can calculate the average cost of delay per resident at 6.5 cents or 13 cents within the interval used in our calculations.

Table 24. Rail passengers time annual time costs from delays in major cities.

	Major cities	**Population**	**Estimated costs, 1 000 euro / year, ppp-adjusted**
Scandinavian (North European)	SAINT PETERSBURG	**4 661 219**	**126 – 261**
	STOCKHOLM	**1 252 020**	**79 – 159**
	COPENHAGEN	**1 189 231**	**90 – 179**
	HELSINKI MA	**1 029 773**	**76 – 152**
	OSLO	**907 288**	**71 –141**
Temperate (Eastern & Central)	BERLIN	**3 440 441**	**190 – 379**
	PARIS	**2 203 817**	**130 – 261**
	HAMBURG	**1 773 218**	**98 – 195**
	WARSAW	**1 711 466**	**57 – 113**
	COLOGNE	**1 000 298**	**55 – 110**
	BUDAPEST	**1 721 556**	**60 – 119**
Alpine	VIENNA	**1 712 903**	**97 – 194**
	MILAN	**1 311 741**	**72 – 144**
	MUNICH	**1 356 594**	**75 – 150**
	TURIN	**909 960**	**50 – 100**
Mediterranean	MADRID	**3 255 944**	**167 – 333**
	ROME	**2 756 502**	**151 – 302**
	BUCHAREST	**1 944 367**	**60 – 121**
	BELGRAD	**1 594 000**	**62 – 125**
	BARCELONA	**1 621 537**	**83 – 166**
Maritime (Oceanic)	LONDON	**7 556 900**	**401 – 802**
	BIRMINGHAM	**1 016 800**	**54 – 108**
	LEEDS	**770 800**	**41 – 82**
	GLASGOW	**581 900**	**31 – 62**
	SHEFFIELD	**534 500**	**28 – 57**
Total		**23 108 343**	**2 326 – 4 652**

The results obtained will vary, if the share of rail commuters out of total amount of commuters is different. These results can be updated with exact shares of commuters for cities where the data are available.

3.3.3 Aviation

For aviation, the calculations are done in a different manner from road and rail, using specific data on the flights from major European airports. In order to determine the time costs borne by society, we use the following calculation method:

1. In each of the climate zones major airports were selected, as defined by the number of departures per year.
2. Based on the assumption that the amount of departures equals the amount of arrivals within a time period of a year, total amount of movements per year per airport were determined.
3. Using analysis of the flight plan and the specific fleet mix at each airport offered by e.g. Flightstats (Flightstats, Global Flight Status and Airport Information, 2012) the percentage of heavy and medium jets is elaborated in a next step with the amount of light ones at major airports being negligible.
4. Based on the fundamentals explained before, input data such as the average seating capacity for heavy and medium jets, average seat load factors and the Value of time (VOT) on today's bases (2010) as well as in future (2040/2070) need to be determined. Relying on guidelines for economic analyses given by EUROCONTROL (2009) and the Civil Aviation Safety Authority (2010) the average seat capacity for heavy jets is assessed with 300 and 120 seats for medium jets. Besides, average seat load factor is set with 75 % in medium jets and 80 % in heavy jets preferentially used for long-haul flights.
5. As for the next step, the average number of passengers in medium and heavy jets per year at the selected airports is determined respectively.

Definition of the value of time (VOT) has been done according to the guidelines recommended in EUROCONTROL (2009) with the VOT being 23 € per hour for leisure and 47 € per hour for business related purposes in 2010 scenario. Values of 63 € per hour (business) and 26 € per hour (leisure) represent the VOT in future scenarios (2040/2070). The proportion of business to leisure travellers was set at 50/50 split.

By the implementation of a time cost factor, changes in the delay levels can be assessed in sensitivity analyses. As not all relevant weather phenomena shown below lead to delays of up to one hour, values for 15min- up to 60min delays have been calculated by using this factor.

Relying EWENT work package 1 results (Leviäkangas et al., 2011), threshold values and their particular impact on the transport mode were defined for the several weather phenomena.

As constituted in this work package, most important weather phenomena for aviation in terms of delays and cancellations are:

- Fog
- Heavy wind
- Cold temperatures.

The average number of days with extreme weather is obtained from the ATM Airport Performance (ATMAP) Framework (EUROCONTROL, 2009b) showing that airports in the Scandinavian region are facing cold temperatures whereas airports like Milan Malpensa or Munich are affected by heavy fog, especially in the morning hours. As some airports are hit by all or at least more than one selected phenomena, the most significant one is used for calculation only. Doing so prevents double –counting of the days and final costs for airlines do not take such days into calculation.

From the society's point of view, the economic loss is the loss of productivity as a consequence of the time spent waiting. In the aviation industry the figures are defined universally, making a study of the impact at the European level easier than in other transport modes, where national values are used.

Calculation of time losses is done as follows:

$$\frac{Paxe}{M_{jets} \cdot year} \cdot VOT(scenario) \cdot Weather_{phenomena}(scenario) \cdot \ time_{factor}$$

with $\frac{Paxe}{M_{jets \ \cdot \ year}}$ = Number of passengers per medium jets per year

$VOT(scenario)$ = Value of time (depending on the selected scenario respectively)

$Weather_{phenomena}(scenario)$ = Average amount of day with the most significant weather Phenomena (depending on the selected scenario respectively)

$time_{factor}$ = Time cost factor (delay measured in euros)

The same procedure has been done for passengers in medium jets for passengers for 2040 as well as for passengers in heavy jets for 2010 and 2040/2070 scenarios with the grand total being calculated as the sum of the respective values.

An overview of the results for three selected airports (London Heathrow, Amsterdam and Zurich) is shown in following Figure 10.

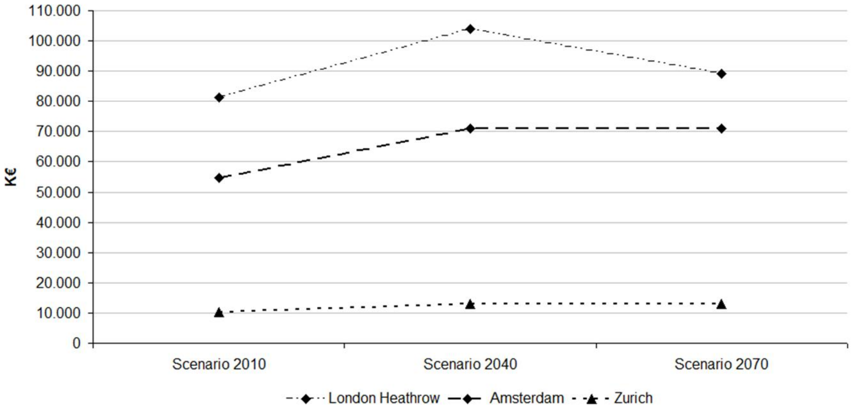


Figure 10. Average total daily social costs caused by extreme weather.

The amount of the financial burden to the society due to different delay levels resulting from extreme weather events are gained by sensitivity analyses. By changing the time cost factor, values for 15 min- up to 60 min delays have been calculated. An overview of the total daily social costs at selected airports for 2010 and for 2040 is given by following Figure 11 and Figure 12.

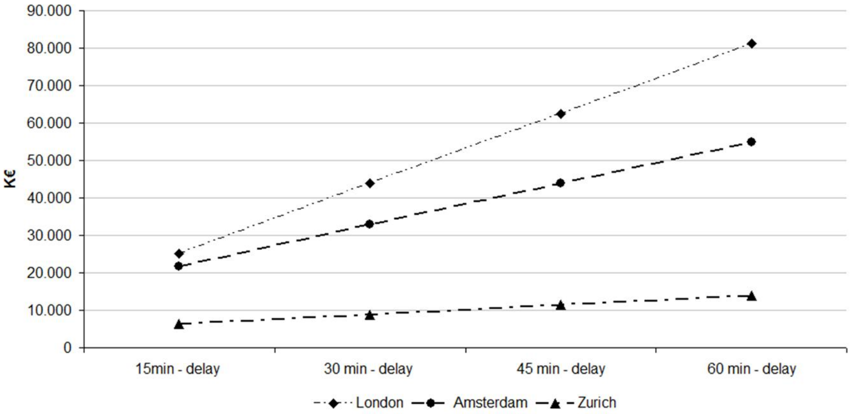


Figure 11. Average total daily social costs at different delay levels due to extreme weather in 2010 scenario.

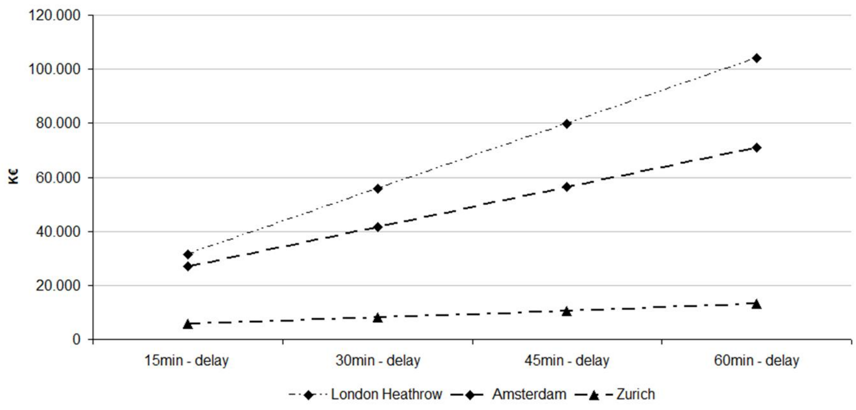


Figure 12. Average total daily social costs at different delay levels due to extreme weather in 2040 scenario.

As can been seen in these Figure 11 and Figure 12, total daily social costs will increase in the future due to changes in weather and higher VOT assumed (see explanation above). However, the rate of increase depends on airport specific performance values as well as local weather phenomena detected. Besides, it needs to be underlined that no changes in traffic volume are taken into account. In case of intentions of expanding capacities at airports resulting in higher total movements per time period, even higher values can be expected.

In addition to the airports studied in greater detail because of their data availability, a similar method was applied to assessing a larger group of major airports in Europe. For these analyses the data from 3 airports analysed were used to provide fleet breakdown as for the previously presented calculations.

3.3.4 Inland waterways and marine/short-sea shipping

Since inland waterways are mainly dealing with freight transport, no calculations were provided for time costs on passenger transport. The issues of freight transport will be addressed in following sections.

In marine and short-sea transport there are only a few routes in the European scale where large volumes of passengers are involved on a daily basis. This, for the passenger transport, leads to considerably small impact, when contrasted with other transport modes.

One of the particular features of passenger transport in marine/short-sea shipping is that the travel is mainly for leisure travel, not for commuting purposes. Again, perhaps some commuting route like the English Canal or Malmö, Sweden to Copenhagen, Denmark offers examples of commuting patterns as well, but in the European scale such travel is very marginal part of the transport system.

As with inland waterways, the impact of time costs are very small, compared to other transport modes. Thus, to conclude, there is no real significant time factor involved in passenger transport in the marine and short-sea shipping in European sea transport.

3.3.5 Freight operators' and shippers' costs

As to freight costs, the up-scaled unit values derived from selected studies can be used as a proxy. When we know the annual freight volumes and share of extreme weather impacts, it is possible to assess the total time costs. The challenge is to assess the number of delay hours which are due to extreme weather impacts. Such data could not be found and we have to apply another proxy, which requires quite strong assumptions.

For freight trains the punctuality has been above 90% during recent years in Nordic and some other European countries, and at least 80% on average for the rest of the Member States (European Commission, 2008). Punctuality means less than 5 minute deviation from the scheduled departure and arrival. Of this fraction of delays we would have to extract the impact of extreme weather and furthermore, assess the average number of minutes or hours that these delays are. This data is not available, but some reference studies can be found.

Based on UK rail statistics published by The British Rail Safety and Standards Board (2010) (see also Bläsche et al., 2011), the UK rail incidents included several weather induced events: flooding and landslips, buckled rails and trains hitting objects blown onto the lines. Flooding, landslips and buckled rails are precursors that belong to the "infrastructure" category. Objects blown to the track belong to obvious category "objects on the line". Wind and rain induced incidents dominate the picture. Altogether these weather induced events represent about 6% of the total number of system failures, mostly related to rail infrastructure.

Duinmeijer and Bouwkegt (2009) reported that about 5% of the rail system failures in Netherlands in 2003 were attributed to weather. High temperatures, icing, storms and thunder strikes were the most common reasons. However, they estimated that the more correct figure could about 10% if the reporting system were better.

The Federal Railroad Administration database was analysed by Rosetti for 1995–2005 and the weather induced incidents formed slightly over 2% of the total. Most common cases were temperature extremes (heat, cold, ice) that caused derailments and liquid precipitation. US rail system is not mostly electrified which reduces the number of incidents related to electric power supply (thunder, trees on electric lines, etc.).

At least for the Oceanic (Maritime) climate zone a proxy of 5% seems to be a viable one. This ratio can be used to assess both accident and time costs. A system disruptive event can lead to either or both and having the aggregate data on consequences, i.e. accidents and delays, an approximate can be given, since there is no reason to assume that weather induced incidents would lead to any less harmful consequences than on average.

Hence, if we assume that 90% of the trains are on time, and from the remaining 10% about 2%–10% would be caused by extreme weather, we end up with a proxy of 0.2%-1% of the freight transports being delayed or stopped by extreme weather. The reference studies do not give any indication how long the delay is. The average delay in case of extreme weather is probably somewhat significant, i.e. it is more likely to be a question of hours than minutes. If this assumption is correct, about one hour average delay would serve as a lower boundary proxy.

For other modes of transport, the data is even scarcer. It is likely that for road freight the delays are more frequent but less severe. For maritime transport the time sensitivity is not perhaps that critical of an issue. For aviation, the time criticality is obvious, but the volumes are very low.

In sum, in order to reach some benchmark figures for freight delay costs, we use the rail's reference results, assuming that 0.2%–1% of the transports of all modes suffer from at least one hour delay due to extreme weather. This is, as said, just a benchmark estimate, not a true approximate for European freight. Apparently this area of interest requires more thorough research to build up a reasonable empirical material on which more accurate estimates can be built.

Below Table 25 presents the unit values derived in Ludvigsen et al. (2012) and the proxies for freight transport delay costs to European shippers. Freight hauliers' costs are estimated only for road hauliers.

Table 25. Time delay costs to European shippers for all modes and road hauliers' costs.

Mode	**Price level adjusted delay unit costs for EU27 €/tonne/hour**		**Annual volume mill. tonnes**[1]	**Extreme weather delay cost (0.2%-1%) million €/year**
	Shippers'	Hauliers'		
Road	9.10	32.8	14 248	Shippers: 300–1 300 Hauliers: 900–4 600
Rail	1.65	x	1 454	4.8–24
IWT	0.079	x	421	0.07–0.33
Sea	0.028	x	3 446	0.19–0.96
Air[2]	227	x	1	0.45–2.3
TOTAL FOR EU'S SHIPPERS				306–1 328
[1] Year 2009, Eurostat, [2] Inside EU-27, Eurostat				

In practice, the road freight dominates the whole picture. Even if one changes quite radically the assumptions, it is highly likely that the pattern does not change too much. All in all, the European shippers lose about 300 million euros per year in minimum due to extreme weather. The upper level proxy is 1.3 billion euros annually. The road hauliers' costs are even more substantial under the above assumptions, yielding to almost 5 billion euros per year. It is somewhat surprising to see that air freight operators' losses could be larger than those of rail and waterborne freight operators'.

To give the first benchmark, the losses of extreme weather resulted time delays for European freight shippers, operators and hauliers is a significant sum, perhaps somewhere between 2 and 7 billion euros each year, with price level of 2009.

4. Future costs

4.1 Future prices and contexts

In principle, several adjustment mechanisms are possible to consider from present state to the selected future states in 2040 and 2070. First of all, do we assume major changes in population, vehicle fleet in different transport modes or improvements in safety and information systems? Given the historical trends, it is likely that the situation in 30 or 60 years' time from today will differ from today in many ways. However, since we are concerned with the relationship between extreme weather and its consequences to transport by transport mode, we cannot (in a plausible way) develop scenarios to cover all prospective changes. We can focus on discussion related to values on two variables that are relevant. One is the pricing decisions (value of time, accidents) and the other one is trends in traffic with respect to defined goals of reduction of accidents. These two variables are quite essential in understanding the changes in future impacts of extreme weather.

To begin with pricing decisions, we can note that the present analyses will utilise defined European values of travel time and accidents, which are normalised for countries and regions using the purchasing power parity as means to take into consideration different income levels. At present the valuations for individual countries are done using in each country data on income levels. It is likely that the present income levels will change considerably in the future, especially when the time frame is as long as in the analyses carried out in this project. We would therefore refrain from adjusting the values, but instead allow for opportunity to compare the impacts by region, where the present levels of income will determine the total impact at regional level.

The decision means, that most likely the figures reported will represent the low end estimate of future costs to transport system. We can present some sensitivity analyses, but these should be treated with caution. This is because we can make several different types of assumptions, for instance regarding different income growth rates in different regions analysed. In the case of aviation, we have used the lower level estimates of present situation for calculations of 2010 time costs and the upper level for 2040 and 2070. Otherwise we have refrained from price adjustments in the analyses. This is not necessary anyhow, as we present the future costs in nominal terms using selected current pricing.

With regards to number of accidents, there are several studies that have estimated the total number of accidents in Europe in the future. This is based on European Union's policy papers on transport safety. In many Member States national safety policies have also indicated that the future targets can be quantified. At present we have trend calculations available up to 2030 (based on CODIA and eCALL estimates), which were extended to 2040 (and 2070) with assumptions of trends in size of vehicle fleet and reduction of accidents due to various types of safety measures.

4.2 Trends in extreme weather

4.2.1 Summary of extreme weather changes until ca. 2050

In sum, the weather extremes do not show radically significant increase trends, but some notable signals are identifiable. In general the climate is warming according to the models used in EWENT and the heat related problems are probably understated in many places. Particularly Mediterranean climate zone is at risk, as is well known. Snow and cold are in general a strongly declining phenomena in pace with the warming. However, the extreme snowfalls are predicted to increase in Northern most parts of Europe. Precipitation as water in general is predicted to increase which goes logically hand in hand in the decreasing of snowfalls. This may mean increased risks in flooding. Obviously, in Alpine areas the warming and rain will enhance this risk. In the Mediterranean, the combination of increased heat waves and precipitation can lead to an increased number of sudden erosions, like landslides. The risk of forest and bush fires will most probably increase everywhere, where heat waves are experienced more frequently.

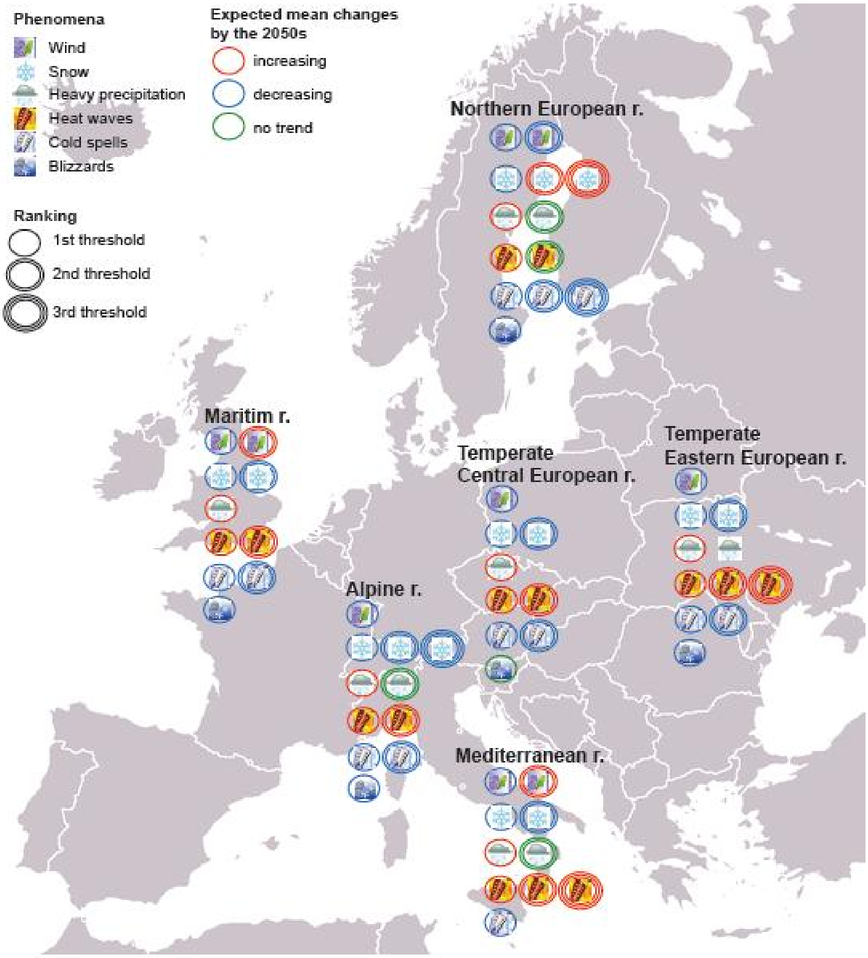


Figure 13. Summary of extreme weather trends for different thresholds (1st = consequences possible, 2nd= consequences likely, 3rd=consequences almost certain) (Tuomenvirta, 2012)

4.2.2 Change for 2011–2040

We can estimate the changes in accident costs and time costs over time by using the changes in weather as a variable to analyse the likelihood of such events in the future. The following tables show the changes between 2011 and 2040 for road, marine and air transport. **In the original analyses the upper, lower and mean values were calculated; what are presented below are the changes in**

mean values of extreme weather projections. No sensitivity analyses were carried out, as the future forecasts and estimates up to 2040 and 2040 contain substantial uncertainties themselves. The venues represent the climatological zones they are located in, and tend to show a trend of the developments as the general trend of change appears to be same in most venues within a zone.

The biggest changes take place in terms of temperatures, which both become more hot overall (Table 26). In some of the case study cities this leads to more hot summers taking place, as changes in heat waves up to nearly 30 per cent (for instance Barcelona in the Maritime region) take place. In general, the trend appears to be that winters will become milder with less cold spells and summers become longer and average temperatures during summer will increase.

Table 26. Changes in mean value for extreme weather for selected road corridors for 2011–2040; changes more than 5 days/year to either direction are bolded (Source: Vajda et al., 2011)

Corridor node city (colour refers to climate zone)	**Change of occurrence probability in number of days per year**				
	wind ≥ 17 m/s	*rain ≥ 30 mm/d*	*snow ≥ 1 cm/d*	*heat ≥ 25 C°*	*cold ≤ 0 C°*
SAINT PETERSBURG	-1.1	0.1	-3.0	4.0	**-12**
STOCKHOLM	-1.5	0.1	**-5.4**	0.2	**-12**
COPENHAGEN	0.3	0	-3.0	0	**-9.1**
HELSINKI MA	0	0.1	**-7.7**	0	**-16**
OSLO	-0.3	-0.1	-3.5	0.2	**-9.8**
BERLIN	0	0.1	-2.4	3.9	**-8.4**
PARIS	-0.1	0.3	-1.5	**7.0**	**-5.5**
HAMBURG	1.0	0.1	-2.1	0.1	**-7.3**
WARSAW	0.1	0.2	-3.1	**5.6**	**-8.8**
COLOGNE	-0.4	-0.1	-1.7	4.8	**-6.6**
BUDAPEST	0.2	0.3	-1.7	**11**	**-7.2**
VIENNA	-0.1	0.4	-2.3	**10**	**-8.2**
MILAN	-0.2	-0.2	-0.9	**15**	**-5.1**
MUNICH	0.8	0.4	-3.1	**6.2**	**-10**
TURIN	-1.1	-0.5	-4.5	**12**	**-15**
MADRID	0	-0.1	-0.2	**15**	-1.7
ROME	-0.4	0.2	0.0	**20**	0.5
BUCHAREST	-0.6	0	-1.3	**13**	**-7.7**
BELGRAD	0.2	0.2	-1.2	**13**	**-5.4**
BARCELONA	0.4	0.2	0	**29**	0.1
LONDON	0.2	0	-1.4	2.8	**-5.0**
BIRMINGHAM	-0.2	0.1	-1.4	2.1	**-5.5**
LEEDS	0	0.1	-2.0	0.8	**-6.7**
GLASGOW	-0.5	0.3	-1.4	0.2	**-5.6**
SHEFFIELD	-0.1	0	-2.0	0.9	**-6.5**

colours depict climate zones

For ports, (Table 27) the situation is very similar to that for roads. In the Nordic regions the winter temperatures become slightly colder and in the Mediterranean region the temperatures continue to become warmer.

Table 27. Changes of extreme weather in selected ports for 2011–2040; changes exceeding 5 days/year to either direction in bold (Source: Vajda et al., 2011)

Port (colour refers to climate zone)	**Change of occurrence probability in number of days per year**				
	wind ≥ 17 m/s	*rain ≥ 30 mm/d*	*snow ≥ 1cm/d*	*heat ≥ 25 C°*	*cold ≤ 0 C°*
Primorsk	-0.9	0.1	**-6.2**	0.2	**-14**
Bergen	-1.5	1.2	-4.0	0	**-9.0**
Gothenburg	-1.2	0.3	-2.6	0.1	**-7.8**
Tallinn	-1.2	0	**-5.9**	1.0	**-14**
Riga	-1.1	0.2	-4.3	2.7	**-12**
Rotterdam	1.5	0.2	-1.2	0.9	-3.7
Antwerp	0.6	0	-1.5	3.6	**-5.4**
Hamburg	1.0	0.1	-2.1	2.7	**-7.3**
Amsterdam	1.2	0.2	-1.8	0.9	-4.9
Le Havre	0.9	0.3	-0.8	3.6	-3.6
Marseilles	0	-0.1	0	**15**	-0.3
Algeciras	1.2	-0.7	0	**14**	0
Valencia	1.5	0.2	0	**16**	-0.1
Genoa	-0.6	-0,5	-0.5	**15**	-2.7
Odessa	0.1	0.1	-2.0	**17**	**-8.1**
Grimsby&Immingham	1.1	0.1	-1.4	0.6	-4.7
London	0.2	0	-1.4	2.8	**-5.0**
Milford Haven	1.6	0.4	-0.2	0.1	-1.5
Dublin	0.9	0.3	-0.8	0.2	-3.2

colours depict climate zones

For airports, the cold waves again become more frequent with snowfall being more of an issue in some Nordic airports. Table 28 below presents the airports from WP 3 selection for which data on annual weather disruptions were available.

Table 28. Changes in extreme weather for selected airports for 2011–2040; changes exceeding 5 days/year are in bold (Source: Vajda et al. 2011)

Airport (colour refers to similar climate zones)	**Change of occurrence probability in number of days per year**				
	wind ≥ 17 m/s	*rain ≥ 30 mm/d*	*snow ≥ 1cm/d*	*heat ≥ 25 C°*	*cold ≤ 0 C°*
LONDON HEATHROW	0.2	0	-1.4	not considered relevant	**-5.0**
MUNICH	0.8	0.4	-3.1		**-10**
ROME FIUMICINO	-0.4	0.2	0		0.5
PARIS CHARLES DE GAULLE	-0.1	0.3	-1.5		**-5.5**
FRANKFURT MAIN	-0.1	0.2	-1.7		**-7.9**
AMSTERDAM SCHIPHOL	1.2	0.2	-1.8		-0.5
BRUSSELS NATIONAL	0.1	0.2	-1.8		**-6.1**
COPENHAGEN – KASTRUP	0.3	0	-3.0		**-9.1**

OSLO – GARDEMOEN	-0.3	-0.1	-3.5		**-9.8**
STOCKHOLM – ARLANDA	-1.5	0.1	**-5.4**		**-12**
HELSINKI – VANTAA	0	0.1	**-7.7**		**-16**
SAINT PETERSBURG	-1.1	0.1	-4.6		**-12**
VIENNA SCHWECHAT	-0.1	0.4	-2.3		**-8.2**
ZURICH	0.2	0.7	-4.0		**-11**
MILAN MALPENSA	-0.2	-0.2	-0.9		**-5.1**
MADRID BARAJAS	0	-0.1	-0.2		-1.7
BARCELONA	0.4	0.2	0.0		0.1
ISTANBUL – ATATURK	2.5	0.3	-0.2		-0.9
ATHENS E. VENIZELOS	1.6	0.1	0		-0.6
LONDON GATWICK	0.2	0	-1.4		**-5.0**
DUBLIN	0.9	0.3	-0.8		-3.2
MANCHESTER	-0.1	0.3	-2.9		**-7.0**

colours depict climate zones

4.2.3 Changes until 2040–2070

The projected changes from present to 2040–2070 are in Vajda et al (2011). These are presented for selected node points and corridors in the tables below (Table 29, Table 30 and Table 31).

Table 29. Changes in extreme weather for the selected road corridors until 2040–2070 (Source: Vajda et al., 2011)

Road corridor cities	**Change of occurrence probability in number of days per year**				
	wind ≥ 17 m/s	*rain ≥ 30 mm/d*	*snow ≥ 1 cm/d*	*heat ≥ 25 C°*	*cold ≤ 0 C°*
SAINT PETERSBURG	-1.5	0.3	**-11**	4.1	**-31**
STOCKHOLM	-0.9	0.2	**-12**	1.3	**-33**
COPENHAGEN	-0.5	0.1	**-7.8**	0.4	**-25**
HELSINKI MA	-0.3	0.3	**-14**	0.4	**-41**
OSLO	-0.2	0.1	**-10**	1.1	**-29**
BERLIN	-0.2	0.3	**-5.7**	**8.3**	**-21**
PARIS	-1.3	0.3	-2.6	**18**	**-9.9**
HAMBURG	0.5	0.3	**-5.9**	**6.4**	**-19**
WARSAW	0.2	0.3	**-7.4**	**12**	**-25**
COLOGNE	-1.1	0.2	-3.6	**12**	**-14**
BUDAPEST	0.3	0.3	-4.5	**22**	**-19**
VIENNA	-0.1	0.4	-4.7	**21**	**-19**
MILAN	-0.1	0.2	-1.3	**28**	**-12**
MUNICH	-0.3	0.3	**-7.4**	**16**	**-20**
TURIN	**-5.8**	-0.6	**-7.4**	**27**	**-29**
MADRID	-0.2	0.2	-0.4	**30**	-3.3
ROME	-1.3	0.4	0	**41**	-0.7
BUCHAREST	-0.8	0.4	-2.9	**25**	**-16**
BELGRAD	-0.1	0.2	-2.9	**27**	**-12**
BARCELONA	-1.4	0	0	**36**	-0.2
LONDON	-0.9	0.2	-2.3	**7.6**	**-9.3**
BIRMINGHAM	-2.5	0.3	-2.3	**5.8**	**-10**
LEEDS	-2.3	0.2	-3.9	2.3	**-12**

GLASGOW	-2.0	0.6	-2.7	0.5	**-11**
SHEFFIELD	-1.9	0.2	-3.6	3.1	**-12**
Note: Changes exceeding 5 days per year in **BOLD.** Colours refer to climate zones.					

Table 30. Changes in extreme weather in selected ports until 2040–2070 (Source: Vajda et al., 2011)

	Change of occurrence probability in number of days per year				
Port	*wind ≥ 17 m/s*	*rain ≥ 30 mm/d*	*snow ≥ 1cm/d*	*heat ≥ 25 C°*	*cold ≤ 0 C°*
Primorsk	-2.1	0.3	**-12**	0.7	**-33**
Bergen	-3.0	2.0	**-7.2**	0.1	**-22**
Gothenburg	-1.4	0.5	**-7.8**	1.4	**-24**
Tallin	-1.1	0.4	**-12**	2.8	**-33**
Riga	-1.0	0.3	**-9.5**	**6.5**	**-29**
Rotterdam	-0.7	0.2	-2.0	2.8	**-7.1**
Antwerp	0.2	0.1	-2.5	**10**	**-10**
Hamburg	0.5	0.3	**-5.9**	**6.4**	**-19**
Amsterdam	-0.3	0.4	-3.0	3.8	**-9.3**
Le Havre	-1.0	0.1	-1.2	**9.0**	**-5.9**
Marseilles	-1.0	-0.1	0	**33**	-0.4
Algeciras	4.1	-0.6	0	**31**	0
Valencia	-2.3	0.1	0	**41**	-0.1
Genoa	-1.4	0.1	-0.8	**33**	**-5.5**
Odessa	-1.5	0.4	-3.5	**27**	**-18**
Grimsby&Immingham	-1.2	0.2	-2.4	1.8	**-7.7**
London	-0.9	0.2	-2.3	**7.6**	**-9.3**
Milford Haven	-2.8	1.1	-0.3	0.2	-2.0
Dublin	-3.1	0.6	-1.0	0.4	-4.9
Note: Changes exceeding 5 days per year in **BOLD.** Colours refer to climate zones.					

Table 31. Changes in extreme weather for selected airports until 2040–2070 (Source: Vajda et al., 2011)

Airport	**Change of occurrence probability in number of days per year**				
	wind ≥ 17 m/s	*rain ≥ 30 mm/d*	*snow ≥ 1cm/d*	*heat ≥ 25 C°*	*cold ≤ 0 C°*
LONDON HEATHROW	-0.9	0.2	-2.3	not considered relevant	**-9.3**
MUNICH	-0.3	0.3	**-7.4**		**-20**
ROME FIUMICINO	-1.3	0.4	0		-0.7
PARIS CHARLES DE GAULLE	-1.3	0.3	-2.6		**-9.9**
FRANKFURT MAIN	-0.3	0.3	-4.3		**-17**
AMSTERDAM SCHIPHOL	-0.3	0.4	-3.0		**-9.3**
BRUSSELS NATIONAL	-0.4	0.2	-2.9		**-11**
COPENHAGEN - KASTRUP	-0.5	0.1	**-7.8**		**-25**
OSLO - GARDEMOEN	-0.2	0.1	**-10**		**-29**
STOCKHOLM - ARLANDA	-0.9	0.2	**-12**		**-33**
HELSINKI - VANTAA	-0.3	0.3	**-14**		**-41**
SAINT PETERSBURG	-1.5	0.3	**-11**		**-31**
VIENNA SCHWECHAT	-0.1	0.4	-4.7		**-19**
ZURICH	-0.8	1.3	**-9.6**		**-22**
MILAN MALPENSA	-0.1	0.2	-1.3		**-12**
MADRID BARAJAS	0.2	0.2	-0.4		-3.3
BARCELONA	-1.4	0	0		-0.2
ISTANBUL - ATATURK	1.0	0.2	-0.5		-1.6
ATHENS E. VENIZELOS	0.1	0	-0.1		-1.4
LONDON GATWICK	-0.9	0.2	-2.3		**-9.3**
DUBLIN	-3.1	0.6	-1.0		-4.9
MANCHESTER	-2.5	0.6	**-5.1**		**-14**
Note: Changes exceeding 5 days per year in **BOLD.** Colours refer to climate zones.					

4.3 Future infrastructure related costs

Since there is no precise trend available for the infrastructure related costs, we can utilise the interviews conducted with some of the infrastructure operators as well as the information regarding the weather changes in Europe. This will enable to identify some clear trends. Tables presenting the weather changes between now and 2040 and 2070 can be found in Vajda et al. (2011).

As the results show, in the Nordic countries cold days will become fewer in the winter season. This is likely to correlate with some less winter maintenance works in these regions. As the Southern Europe will have more hot days during the season, the impact on tarmac, for instance, will be an increase in the weariness. However, unlike in the case of winter maintenance the im-pact maybe observed with a delay, making it difficult to establish a firm link between the two.

Table 32 below shows the future patterns of infrastructure damage related costs based on WEATHER project’s analysis (Enei et al., 2011). We attempt to identify the trends in these costs based on extreme weather scenarios, but absolute figures were too challenging to derive within given research framework.

Table 32. Infrastructure damage related costs in the future in different climate zones

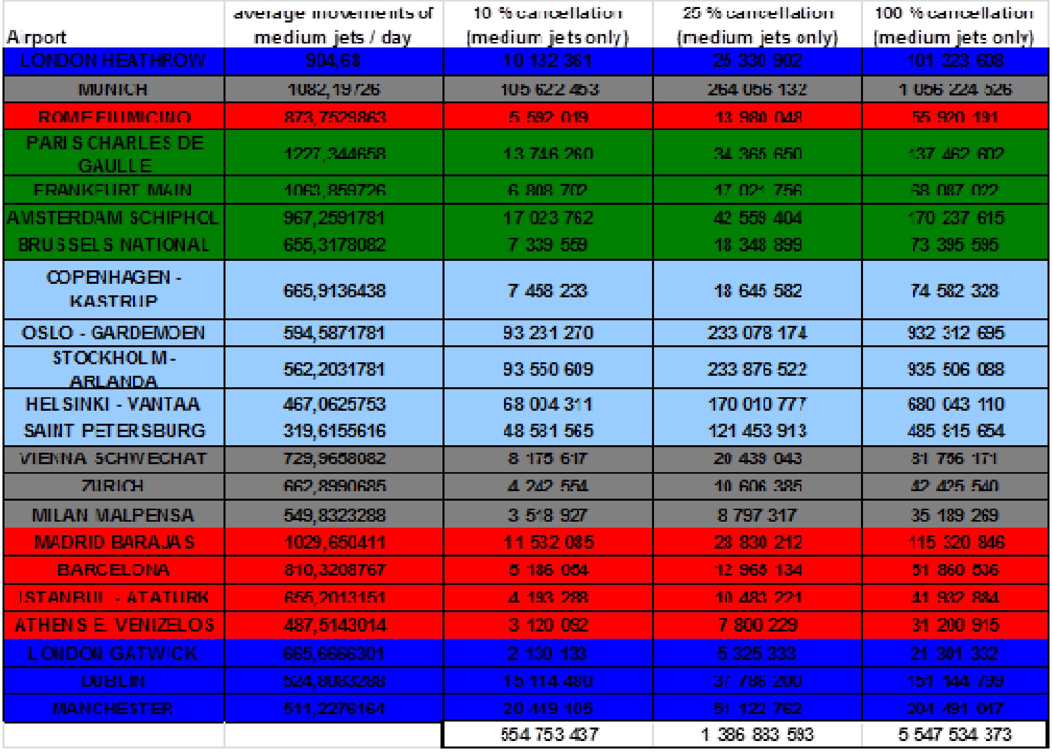
Extreme weather event		***Present costs per event***		***Future cost trend 2040–2070***	
		Infra assets	*Infra operations*	*Infra assets*	*Infra operations*
Storm (winds, heavy rains)	Road	76.10	22.60	There is a slight increase in the Oceanic climate zone; for other zones, no clear indication of change	
	Rail	0.07			
	Maritime	–	–		
	IWT	–	–		
	Air	–	–		
Severe winter (cold, snow)	Road	248.80	126.30	In the Northern European climate zone, the warming winters may deteriorate both the surface and substructures due to more frequent freezing and melting	In the Northern zone, winter maintenance costs are expected to decrease slightly due to the warming
	Rail	0.04			
	Maritime & IWT	–		–	The ice coverage of the Baltic Sea is expected to reduce and thin; the same is expected for IWT routes
Floods & heavy rains	Road	630.10	21.90	In the Oceanic zone, the increase in winds and rains can lead to more flooding and wash-away of the infrastructures; in the Alpine and mountainous zones, the melting of the ice combined with snowfalls turning into water precipitation can have the same effect	In the Oceanic and Alpine and mountainous zones the warming may move snow masses and increase the probability of landslides, increasing heavy duty maintenance and repair works
	Rail	103.66			

4.4 Airline operator costs in 2040 and 2070

Similarly to calculations of present cancellations of flights, estimates of impact of cancellations were calculated for 2040 and 2070, using data on forecasted weather changes as indicators of the future impacts. The results show that the decline in extreme weather conditions, as envisaged by the scenarios of weather developments created in work package 2 of the project (Vajda et al., 2011). There is an overall decrease in costs across all the different assumptions on percentage of flights being cancelled.

By 2070 the total costs of cancellations will have fallen to nearly half of the present level, due to changes in weather conditions across Europe. This is shown in Table 33 below.

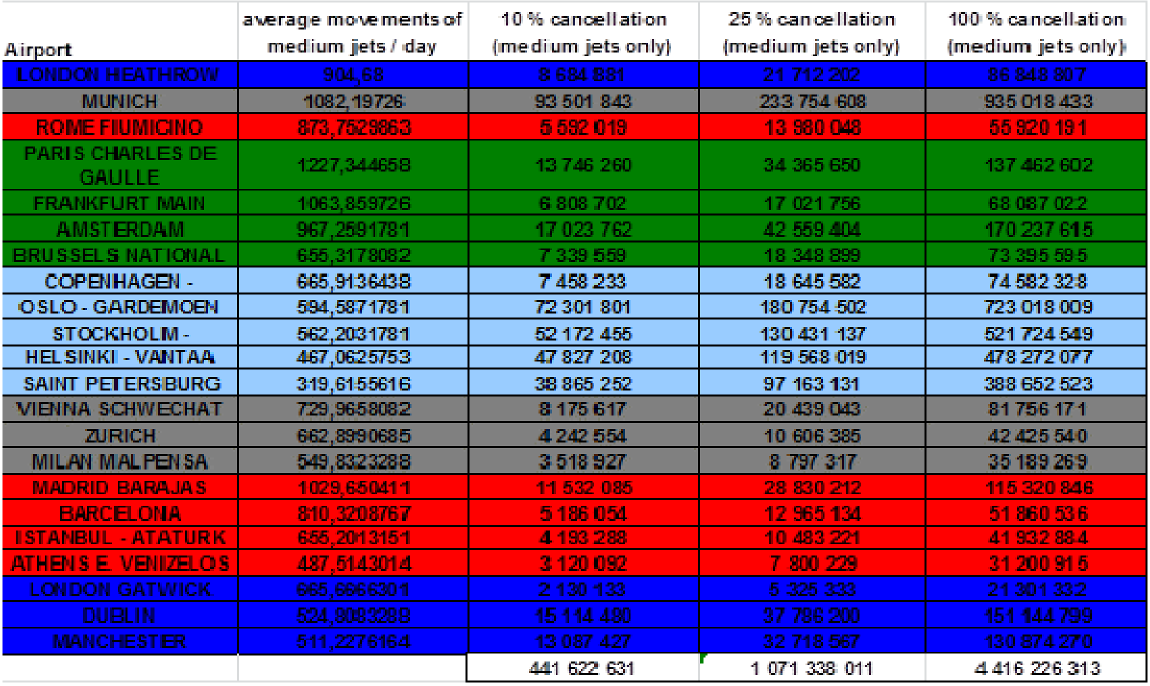
Table 33. Airline operator costs in 2040 (€).



Airport	average movements of medium jets / day	10 % cancellation (medium jets only)	25 % cancellation (medium jets only)	100 % cancellation (medium jets only)
LONDON HEATHROW	904,68	10 132 361	25 330 902	101 323 608
MUNICH	1082,19726	105 622 453	264 056 132	1 056 224 526
ROME FIUMICINO	873,7529863	5 592 019	13 980 048	55 920 191
PARIS CHARLES DE GAULLE	1227,344658	13 746 260	34 365 650	137 462 602
FRANKFURT MAIN	1063,859726	6 808 702	17 021 756	68 087 022
AMSTERDAM SCHIPHOL	967,2591781	17 023 762	42 559 404	170 237 615
BRUSSELS NATIONAL	655,3178082	7 339 559	18 348 899	73 395 595
COPENHAGEN - KASTRUP	665,9136438	7 458 233	18 645 582	74 582 328
OSLO - GARDEMOEN	594,5871781	93 231 270	233 078 174	932 312 695
STOCKHOLM - ARLANDA	562,2031781	93 550 609	233 876 522	935 506 088
HELSINKI - VANTAA	467,0625753	68 004 311	170 010 777	680 043 110
SAINT PETERSBURG	319,6155616	48 581 565	121 453 913	485 815 654
VIENNA SCHWECHAT	729,9658082	8 175 617	20 439 043	81 756 171
ZURICH	662,8990685	4 242 554	10 606 385	42 425 540
MILAN MALPENSA	549,8323288	3 518 927	8 797 317	35 189 269
MADRID BARAJAS	1029,650411	11 532 085	28 830 212	115 320 846
BARCELONA	810,3208767	5 186 054	12 965 134	51 860 536
ISTANBUL - ATATURK	655,2013151	4 193 288	10 483 221	41 932 884
ATHENS E. VENIZELOS	487,5143014	3 120 092	7 800 229	31 200 915
LONDON GATWICK	665,6666301	2 130 133	5 325 333	21 301 332
DUBLIN	524,8083288	15 114 480	37 786 200	151 144 799
MANCHESTER	511,2276164	20 419 105	51 122 762	204 491 017
		554 753 437	1 386 833 593	5 547 534 373

colours depict climate zones; red = Mediterranean, blue = Maritime, grey = Temperate Central, pale blue = Northern

Table 34. Airline operator costs of cancellations in 2070 (€).



Airport	average movements of medium jets / day	10 % cancellation (medium jets only)	25 % cancellation (medium jets only)	100 % cancellation (medium jets only)
LONDON HEATHROW	904,68	8 684 881	21 712 202	86 848 807
MUNICH	1082,19726	93 501 843	233 754 608	935 018 433
ROME FIUMICINO	873,7529863	5 592 019	13 980 048	55 920 191
PARIS CHARLES DE GAULLE	1227,344658	13 746 260	34 365 650	137 462 602
FRANKFURT MAIN	1063,859726	6 808 702	17 021 756	68 087 022
AMSTERDAM	967,2591781	17 023 762	42 559 404	170 237 615
BRUSSELS NATIONAL	655,3178082	7 339 559	18 348 899	73 395 595
COPENHAGEN -	665,9136438	7 458 233	18 645 582	74 582 328
OSLO - GARDEMOEN	594,5871781	72 301 801	180 754 502	723 018 009
STOCKHOLM -	562,2031781	52 172 455	130 431 137	521 724 549
HELSINKI - VANTAA	467,0625753	47 827 208	119 568 019	478 272 077
SAINT PETERSBURG	319,6155616	38 865 252	97 163 131	388 652 523
VIENNA SCHWECHAT	729,9658082	8 175 617	20 439 043	81 756 171
ZURICH	662,8990685	4 242 554	10 606 385	42 425 540
MILAN MALPENSA	549,8323288	3 518 927	8 797 317	35 189 269
MADRID BARAJAS	1029,650411	11 532 085	28 830 212	115 320 846
BARCELONA	810,3208767	5 186 054	12 965 134	51 860 536
ISTANBUL - ATATURK	655,2013151	4 193 288	10 483 221	41 932 884
ATHENS E. VENIZELOS	487,5143014	3 120 092	7 800 229	31 200 915
LONDON GATWICK	665,6666301	2 130 133	5 325 333	21 301 332
DUBLIN	524,8083288	15 114 480	37 786 200	151 144 799
MANCHESTER	511,2276164	13 087 427	32 718 567	130 874 270
		441 622 631	1 071 338 011	4 416 226 313

colours depict climate zones; red = Mediterranean, blue = Maritime, grey = Temperate Central, pale blue = Northern)

Airports appear to be susceptible to fog, wind and cold spells in the future. When fog appears, it will trouble the operations. However, tentative analysis in Vajda et al. (2010) shows that fog could well be a phenomenon that will appear more seldom in the future.

4.5 Trends in accident rates and costs

The occurrence of extreme weather phenomena is interlinked with simultaneous changes in the traffic safety. As we have concluded earlier, the most safe transport mode is aviation, where the amount of accidents has been and will mostly likely remain small. This is despite the growing volumes of passengers in air transport, as the improvements in safety measures will offset the increase in travel volumes.

With inland waterways, similarly, annual amount of accidents has been modest and is not expected to change dramatically in the future. In the marine transport, the key issue is how well the ships' information systems can provide information on extreme weather conditions. Some of the most serious accidents in marine transport have been the result of extreme weather conditions, especially wind and blizzards. Since the amount of marine transport accidents has been relatively small, we consider that there is no major change in the overall amount of accidents between now and the future states we look at. This leaves us with road and rail transport to consider.

There is a type of accident that is very specific for road and rail transport, which is a collision of a vehicle and a train (naturally such accidents do occur in all transport modes except for aviation, but the frequency is much less than that of road and rail transport). These accidents typically take place in level-crossings, where a vehicle crosses the railway tracks. In Europe, there are thousands of such crossings and despite the on-going work to install safety equipment and modify the crossings they will also remain in the future as one of the potential sources of accidents. In particular, weather conditions such as rain, snow, blizzards, low temperatures and fog will remain as potential sources for these types of accidents.

Considering road transport, European countries have set up campaigns to improve road safety. These are likely to impact the current levels of accidents with a declining trend from present to the future states of analyses. To estimate the total level of accidents from 2011 to 2040 and 2070, we use the trends developed in CODIA and eCALL projects (Kulmala et al., 2008; Francsics et al., 2009). From eIMPACT we were also able to establish the ratio of 19 per cent of total accidents being serious. In CODIA, the trend was calculated for 2020 and in the eCALL for 2030. These trends will be now taken further to 2040 and 2070 for fatalities and severe accidents in the road transport (Table 35).

Table 35. Projections of changes in accidents in road transport, baseline (2007) to 2040 and 2070.

Year	Fatalities	Severe injuries	All injuries	Source
2007	49 016	376 251	1 980 269	Eurostat
2020	26 414	240 190	1 264 158	CODIA estimates (Kulmala et al., 2008)
2030	15 422	172 792	909 434	eCALL estimates (Francsics et al., 2009)
2040	12 337	146 874	727 547	Author's estimates
2070	9 253	117 499	545 660	Author's estimates

Using the case studies determined in work package 3, this chapter will provide an estimate of the extreme weather impacts on accidents and the associated costs. The estimates will be conducted for the case studies and extrapolated to cover regions and EU average.

For rail, we assume a similar trend as for road transport in the accident reduction. Thus, for rail the accident statistics would look as presented in *Table* 36 below.

Table 36. Projections of changes in accidents in rail transport, baseline (2008) to 2040 and 2070.

Year	Fatalities	Severe injuries
2008	1 498	1 350
2040	450	650
2070	300	400

Similarly, for inland waterways the trend can be established, as shown in Table 37 below.

Table 37. Projections of changes in accidents in inland waterways, from present to 2040 and 2070.

Year	Fatalities	Severe injuries
Present	1	2
2040	1	2
2070	1	2

Finally, for marine/short-sea shipping the figures are reported below in Table 38.

Table 38. Projections of changes in accidents in marine/short-sea shipping, from present to 2040 and 2070.

Year	Fatalities	Severe injuries
Present	60	420
2040	15	200
2070	12	110

Based on these future estimates of accident levels and the corresponding changes in weather conditions presented in Chapter 4 of this report it is possible to estimate the future costs of extreme weather in terms of accidents.

Calculations made have not paid a great deal of attention to the material damages (mainly to vehicles, trains, ships or planes) in the case of accidents. This is partly because of the fact that most material damages are borne by insurance companies and they do not directly become social costs as such. It can be argued, however, that increasing accident volumes do contribute to higher insurance premiums, which are a form of social cost and can create inequality. From the point of view of analyses, these considerations offer a way of looking at the indirect costs of accidents. Such calculations were not carried out as data were not available.

Table 39 below presents an overview of accident costs in present situation and in 2040 and 2070. Given both the expected developments in vehicle technology and emergency systems, the amount of road accidents is expected to decline significantly. Simultaneously, the fact that climate change is changing temperatures and frequency of extreme weather phenomena causes a major decline in total accidents, and, therefore the associated accident costs. However, it must be taken into consideration that the end result is the sum of the elements, not only attributed to weather changes.

Table 39. The overview of accident costs due to extreme weather at present in EU, and in 2040 and 2070.

Scenario	**Accident costs[1] of extreme weather p.a., excluding material damages and mild injuries (million €)**				
	Roads	*Rail*	*IWT*	*Maritime*	*Aviation*
Present ~2010	20 725	103	1.5	10	~0
2040	6 630	31	1.5	3	~0
2070	4 482	20	1.5	2	~0

[1] 10% of the total number for roads and IWT, 5% for rail and maritime

The road system's accident costs are huge and deserve the most attention from safety perspective, not to understate the significance of all modes' safety, even taking into consideration the general declining trend.

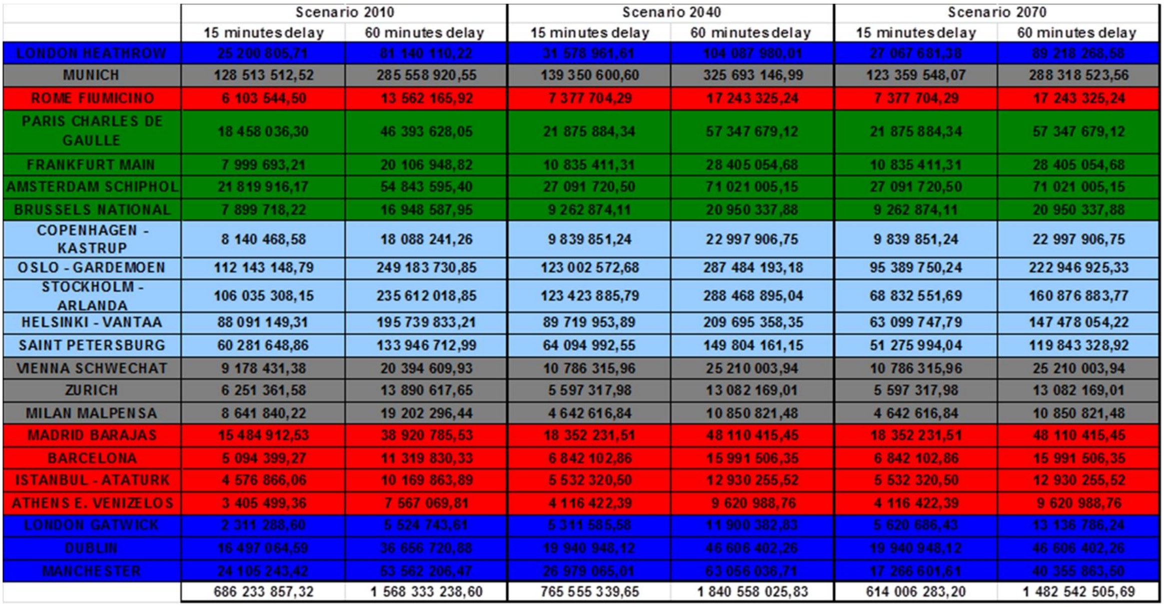
Similar to the situation in 2040, the figures for 2070 also show a drop in total accident costs. The estimate for 2070 is 4 504 million euro for all transport modes. The frequency of extreme weather events continues to decrease during this period, affecting the figures. The average estimate of additional decline in total accidents caused by extreme weather is estimated at 20 per cent from the meteorological forecasts provided in from Vajda et al. (2011) and presented in Table 37 to Table 39. As explained earlier in the calculations, the fact that one or more extreme weather events can and most likely will take place simultaneously means that in general the most interesting change is the biggest overall impact in a region.

4.6 Time cost projections

4.6.1 Aviation – total costs

Considering the total impact in 2040 and 2070 for aviation, Table 40 below shows the impact across 22 airports in Europe.

Table 40. Total costs of delays at selected airports at present and in 2040 and 2070.



	Scenario 2010		Scenario 2040		Scenario 2070	
	15 minutes delay	60 minutes delay	15 minutes delay	60 minutes delay	15 minutes delay	60 minutes delay
LONDON HEATHROW	25 200 805,71	81 140 110,22	31 578 961,61	104 087 980,01	27 067 681,38	89 218 268,58
MUNICH	128 513 512,52	285 558 920,55	139 350 600,60	325 693 146,99	123 359 548,07	288 318 523,56
ROME FIUMICINO	6 103 544,50	13 562 165,92	7 377 704,29	17 243 325,24	7 377 704,29	17 243 325,24
PARIS CHARLES DE GAULLE	18 458 036,30	46 393 628,05	21 875 884,34	57 347 679,12	21 875 884,34	57 347 679,12
FRANKFURT MAIN	7 999 693,21	20 106 948,82	10 835 411,31	28 405 054,68	10 835 411,31	28 405 054,68
AMSTERDAM SCHIPHOL	21 819 916,17	54 843 595,40	27 091 720,50	71 021 005,15	27 091 720,50	71 021 005,15
BRUSSELS NATIONAL	7 899 718,22	16 948 587,95	9 262 874,11	20 950 337,88	9 262 874,11	20 950 337,88
COPENHAGEN - KASTRUP	8 140 468,58	18 088 241,26	9 839 851,24	22 997 906,75	9 839 851,24	22 997 906,75
OSLO - GARDEMOEN	112 143 148,79	249 183 730,85	123 002 572,68	287 484 193,18	95 389 750,24	222 946 925,33
STOCKHOLM - ARLANDA	106 035 308,15	235 612 018,85	123 423 885,79	288 468 895,04	68 832 551,69	160 876 883,77
HELSINKI - VANTAA	88 091 149,31	195 739 833,21	89 719 953,89	209 695 358,35	63 099 747,79	147 478 054,22
SAINT PETERSBURG	60 281 648,86	133 946 712,99	64 094 992,55	149 804 161,15	51 275 994,04	119 843 328,92
VIENNA SCHWECHAT	9 178 431,38	20 394 609,93	10 786 315,96	25 210 003,94	10 786 315,96	25 210 003,94
ZURICH	6 251 361,58	13 890 617,65	5 597 317,98	13 082 169,01	5 597 317,98	13 082 169,01
MILAN MALPENSA	8 641 840,22	19 202 296,44	4 642 616,84	10 850 821,48	4 642 616,84	10 850 821,48
MADRID BARAJAS	15 484 912,53	38 920 785,53	18 352 231,51	48 110 415,45	18 352 231,51	48 110 415,45
BARCELONA	5 094 399,27	11 319 830,33	6 842 102,86	15 991 506,35	6 842 102,86	15 991 506,35
ISTANBUL - ATATURK	4 576 866,06	10 169 863,89	5 532 320,50	12 930 255,52	5 532 320,50	12 930 255,52
ATHENS E. VENIZELOS	3 405 499,36	7 567 069,81	4 116 422,39	9 620 988,76	4 116 422,39	9 620 988,76
LONDON GATWICK	2 311 288,60	5 524 743,61	5 311 585,58	11 900 382,83	5 620 686,43	13 136 786,24
DUBLIN	16 497 064,59	36 656 720,88	19 940 948,12	46 606 402,26	19 940 948,12	46 606 402,26
MANCHESTER	24 105 243,42	53 562 206,47	26 979 065,01	63 056 036,71	17 266 601,61	40 355 863,50
	686 233 857,32	1 568 333 238,60	765 555 339,65	1 840 558 025,83	614 006 283,20	1 482 542 505,69

colours depict climate zones; red = Mediterranean, blue = Maritime, grey = Temperate Central, pale blue = Northern

Table 40 reports the 15 minutes and 60 minutes delay impacts for the days when poor weather was observed at the airports. This calculation assumes that the maximum number of adverse weather days for an airport is the number of days for the worst phenomena for the airport to avoid double-counting of days when more than one phenomenon has occurred.

4.6.2 Passengers' time costs on commuting roads and rails

The case analysis for Helsinki metropolitan area suggested that annual road commuters' time costs due to extreme weather delays were 2–4 euros per area inhabitant per year, totalling approximately to 2–4 million € annually. Much of these costs were resulted by heavy snowfall, 14 days out of 32 extreme weather days, i.e. about half of the events. In other regions the phenomena are different or at least the phenomena will have a different distribution, most likely more emphasised by extreme rains and winds. Hence our estimate is that a most robust estimate for urban road user time costs would be between 1–2 euros per year in any of the cities in any of the climate zones. This estimate is conservative compared to Helsinki area costs, but on the other hand, the phenomena are fewer.

On the other side of the coin there is though the sheer volume of commuting traffic. The more there is traffic, the less there is extra infrastructure capacity and therefore even some milder extremes can have a significant impact. These arguments make the bigger than Helsinki cities more vulnerable to weather extremes.

Table 41. Europe's urbanisation and population development (sources: UN and Eurostat).

	2010		2050	
	Population, mill.	Urbanisation-%	Population, mill.	Urbanisation-%
Europe	503	73	472	84
Northern Europe	–	84	–	91
Western Europe	–	77	–	87
Eastern Europe	–	69	–	80
Southern Europe	–	68	–	81

According to UN statistics[3] Europe's urbanisation in 2010 was 73%, and continues to develop further to 86% until year 2050. However, in different parts of Europe the development is not similar.

This means that there is little change in the number of urban population subjected to extreme weather impacts (2010: ca. 367 mill; 2050: ca. 396 mill.) and these trends do not have any significant effect on future costs.

In sum, the time costs of European road commuting passengers is in the neighbourhood of 500–1 000 million euros per year, not significantly changing in the future ceteris paribus, assuming a cost of 1–2 euros per urban inhabitant.

For rail commuters, the Helsinki case analysis showed a significantly smaller figure, much due to the passenger volumes, being so much lower on rails. The unit cost per urban resident for Helsinki was a fraction that of road commuters' costs, only 6.5–13.0 cents per citizen of the area. This can be added to commuters' costs on roads without making any significant errors of estimation. The same applies to European level up-scaling. One thing that is different in Europe, however, is that rail commuters represent a fair share of all commuting. Such commuting statistics is not unfortunately available. Indirect estimation methods are always possible, but beyond the scope of this project.

4.6.3 Freight time loss projections

We estimated that the present costs of time delays for European shippers and hauliers were roughly between 2–7 billion euros annually, based on unit values

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[3] UN HABITAT, press release, embargoed 18 March 2010.

per freight tonne, and varying between modes. The future costs need to be assessed then on the basis of freight volume projections. The freight volumes in turn depend largely on economic growth experience by the European industries and economies.

Enei (2010) estimated that the European freight volumes would grow on average by 2% annually until 2020, 1.9% until 2030 and 1.4% until 2050. These growth rates are somewhat cautious and based on the use of freight transport models, which rely on number of different estimated variables and their interdependencies. Policies that either favour or punish physical traffic, e.g. on the grounds of environmental policy objectives, are of course significant factors as well – and policy factors are important in both ways: when the policies succeed and when they fail. Furthermore, Enei's analysis assumes higher growth for rail than for road which so far has not been empirically witnessed.

Giving specific growth rates to individual modes always relies on policy measures' impacts projections and assumptions on the industrial structures of EU-27, both of which are worth a long story of their own. Hence, we assume single freight growth rate coming from TRANSVisions project (Enei, 2010) being 1.4% per year until 2050. This means that the freight volumes will increase by 2050 by ca. 74% compared to the present level (52% by 2040, and 130% by 2070) on a compounding basis.

The future costs would then be, as expressed in today's prices, around 3.5 – 12 billion euros each year, borne by European shippers and freight hauliers, assuming that only the volumes of freight grow and all other factors remain constant.

5. Summary, conclusions and recommendations

5.1 General

As explained earlier, the infrastructure costs of extreme weather event are not easy to quantify. Contracts and business secrets make it extremely difficult to get accurate data from operators, in some cases simply because this is not available at the needed level.

In comparison with the results on time and accident costs, we can see that the information available suggests that operators’ costs are less in volume than the social costs. However, they are a merit in their self as they are actual costs to the entities involved, whereas the social costs are more of speculative nature.

From the results we can see that it is very difficult to

a) quantify the unit costs of infrastructure maintenance and repairs; and
b) to be able to say how large a portion of the infrastructure costs is related to extreme weather.

This research suggests that this is one area where more work is to be done in the future. Unified values to be used in the European research would help the researchers to provide calculations and estimates in a more accurate way.

Infrastructure costs are perhaps the area where the least information is available of all types of costs of operating the European transport system. This is due to the fact that such data is not collected at the European level and (obviously) also due to the nature of the industry, with increased subcontracting as already discussed before. The main issue is that in the last decades maintenance costs have to a great extent been outsourced to private companies responsible of day to day operations of the transport network.

This deliverable presents the first ever European level estimates of costs of extreme weather conditions on the transport system. There are several areas where the data available has allowed for in-depth review and others where it has been necessary to arrive to broad conclusion due to poor data availability. Starting with the accidents data, the fact that we have used a European average as an estimate for the entire EU level accidents obviously undermines the country by differences.

This has been partially offset by providing additional climate zone level estimates. However, it does appear that there is really a massive loss at the European level encountered from extreme weather, independent of whether we use a lower level or upper level estimate of the total costs.

For all the analyses conducted, it is easy to understand that any changes in parameters will also change the outcome of calculations. This is why several sensitivity analyses were conducted and presented in this report. This enables to understand the need for better data to support the analysis in the future. As expressed throughout work package 4, data availability is a major concern for estimating accurate European level estimates. The same applies to the issue of time or accident costs. For accidents, we know the European level and country level accidents, but only in few cases we also know exactly or even roughly what proportion of total accidents or delays is a result of the extreme weather phenomena.

More importantly, for accidents we do not know the official valuation of social costs of accidents in most European countries. In countries where such valuations have been a standard element of the transport sector CBA the values exist and they are frequently updated too. It is interesting to note that project evaluations do take place in these countries too but the accident valuations do not seem to play an important role in the assessments. This is contradictory to practice in those countries where transport sector CBA places a high emphasis on accidents costs reduction, which is an integral part of goals set for the transport sector and the subsequent investments. In many cases the valuation of fatalities at 1 million euro or above can bring about significant benefits to small projects aimed to improve the safety of transport system. For future analyses, the existence of official country-by-country values would improve the possibilities to accurately estimate the accident costs.

Time costs do not have a similar radical declining trend as accident costs. There is a slight decline in the extreme weather events based on climatological scenarios, but on the other hand, the traffic volumes are still expected to grow in the future. The more there is traffic load and less capacity in the infrastructure, the less severe weather phenomena will have an adverse impact on traffic flows. These two trends neutralise each other to some extent, but which of the trends is the dominant one, is harder to assess. Needless to point out, both trends are highly uncertain, unlike accident trends which do have a long empirical time series.

Similarly for values of time, traditional approach is to consider the reduction in travel time as a result of the transport sector investments. New projects are aimed to increase mobility and thus the discussion is focused on travel time savings. In the context of extreme weather the focus is on travel time lost, which is contrary to the thinking behind CBA calculations. However, one feature of the travel time losses is similar to that of the transport project CBA: all users are impacted by same amount, as the delays are affecting all passengers if and when congestion results from adverse weather. This is the same result for aviation as it is for road or rail. But again values of time are not available for all Member States, making it necessary to use proxies or regionally representative values to calculate time losses in those countries where no official values are available.

What can we conclude on the way forward? For transport planners to understand the massive nature of the adverse impact on transport system and the users of the system is critical. Only this realisation can lead to effective measures to mitigate the adverse impacts. Suggestions on how to do proper mitigation should be both transport mode specific as well as horizontally addressing the inter- and co-modality of transport system. For researchers, getting more information on country level costs and incidence will definitely improve the calculations towards more rigorous country/regional development plans. The figures presented in this report suggest that at present the total impact of adverse weather on European transport system is greatly underestimated. This will naturally have policy implications in the future design of more weather-resistant solutions to transport network planning and design.

5.2 Present and future costs of extreme weather in Europe

The below table summarises the cost analysis findings. Needless to point out, the figures are very rough benchmarks and bring in the magnitudes of different cost items resulted by extreme weather phenomena, but do not necessarily represent any specific contexts, regions or cases. What is evident, is that road sector costs dominate the picture quite clearly. This is because of one main reason only: most of the transport is done on roads. If relative cost analysis would have been used, the picture might be slightly different, though not too much. Roads are still today relatively unsafe and due to the nature of road network, the vulnerability is high: roads are everywhere and they are not managed as systematically as other networks.

Table 42. Extreme weather resulted costs for the European transport system at present.

Mode	Present costs due to extreme weather, including all phenomena (ca. 2010)				
	Accidents	Time costs	Infrastructure		Freight & logistics
			Physical infra	Maintenance	
Road	**>10 bill. €/a,** mostly borne by the society	**0.5–1.0 bill. €/a,** mostly borne by road commuters	**ca. 1 bill. €/a**, mostly borne by infrastructure managers, ultimately by the taxpayers	**ca. 0.2 bill. €/a**, mostly borne by public infrastructure managers and hence ultimately by the taxpayers	**1–6 bill. €/a,** mostly borne by the shippers
Rail	**>0.1 bill. €/a**, mostly borne by the society	**>10 mill. €/a,** borne by the commuters	**>0.1 bill. €/a,** mostly borne by rail infrastructure managers (=taxpayers)		**5–24 mill. €/a**, borne by the shippers
IWT	**ca. 2 mill. €/a,** mostly borne by society	na	na	na	**0.1–0.3 mill. €/a,** borne by the shippers
Short sea	**>10 mill. €/a,** mostly borne by society	na	na	na	**0.2–1 mill. €/a**, borne by the shippers
Aviation	na	**>0.7 bill. €/a**	na	na	**0.5–2.3 mill. €/a,** borne by the shippers
Light traffic (Mühlhausen 2011)	**>2 bill. €/a,** borne by the society and insurers	–	na	na	–
TOTAL	*>12 bill. €/a*	*>1.2 bill. €/a*	*ca. 1 bill. €/a*	*>0.3 bill. €/a*	*1–6 bill.€/a*
The EU-27 grand total for all modes and all cost items is at present more than 15 bill. euros p.a.					

As to the future costs, there is an apparent trend in declining accident costs, first and foremost because of general trends, and secondly because the winters are getting shorter and warmer in the Northern hemisphere. Icy and slippery roads raise the accident risk up to 2–3 times higher than on dry roads. The winter maintenance operations costs are also expected to decrease throughout Northern Europe. But the actual impact of more frequent weather extremes remains still an open question. However, the magnitudes of that, even if these extremes would become more frequent, will not be that significant compared to the big picture. Natural catastrophes and extremes that bring societies to their knees are of course another chapter. In road transport, as the data on estimated future accident levels shows there will be considerable improvements in vehicle technologies that will contribute to greater safety for passengers. Thus, the scenarios take these developments into consideration as given baseline of future accident volume developments.

The following table attempts to capture the relevant changes in costs due to climatological changes. For many items, the changes are positive, but not all. In aviation, the trend is to see costs from delays to go up by 2040 from present mainly due to value of time changes but declining by 2070 as events become less frequent.

Table 43. Future costs (present price level) of extreme weather resulted consequences to European transport system.

Mode	Future costs of extreme weather, including all phenomena (period 2040–2070)				
	Accidents	Time costs	Infrastructure		Freight & logistics
			Physical infra	Maintenance	
Road	**4.5–6.6 bill. €/a,** mostly borne by the society	**0.5–1.0 bill. €/a,** will remain about the same	**ca. 1 bill. €/a**, will remain about the same	**<0.2 bill. €/a**, will reduce due to less need for wintermaintenance	**2–10 bill. €/a,** will increase significantly, if volumes continue to grow
Rail	**<0.3 bill. €/a**, mostly borne by the society	**>10 mill. €/a,** borne by the commuters	**ca. 0.1 bill. €/a**, will remain about the same; winter maintenance will decrease, but other costs may increase		**8–41 mill. €/a**, will increase in pace with freight volumes
IWT	**ca. 2 mill. €/a,** mostly borne by society	na	na	na	**0.2–0.5 mill. €/a,** will increase in pace with volumes
Short sea	**<3 mill. €/a,** mostly borne by society	na	na	Will decrease due to less need for ice-breaking	**0.3–1.7 mill. €/a**, will increase in pace with volumes
Aviation	na	**0.6–0.8 bill. €/a** will increase by 2040 but drops by 2070	na	na	**0.8–4 mill. €/a**
Light traffic	**will likely reduce**	–	na	na	–
TOTAL	*>6 bill. €/a*	*ca. 1 bill. €/a*	*ca. 1 bill. €/a*	*<0.3 bill. €/a*	*2–10 bill.€/a*
The EU-27 grand total for all modes and all cost items will be more than 10 bill. euros p.a.					

Even with the above elementary analysis, the pattern clears. Much of the decrease in accident costs will be off-set by increase in time delay costs, especially if the freight volumes continue to grow at an anticipated pace. The time costs of passengers in turn do not grow at the same pace simply because Europe's declining population which the urbanisation trend is not really neutralising when thinking of urban commuter volumes.

Infrastructure costs are expected to remain approximately at the current level, but there is possibly an internal shift from winter maintenance to increased damages if heavy rains and floods become more frequent. The ageing of the infrastructures will certainly not dampen these consequences.

5.3 Strategic options and distributional effect considerations

The technologies developed for road vehicles have made a significant contribution to the development of safety trends in the road sector. Automotive industry has clearly performed well in this respect and the markets for both supply and demand of safety technologies have been efficient. Our cars are safer than ever before. Anti-skid technologies, airbags, lane-keeping aids, visual recognitions with help of infrared and radars, etc. have all contributed to safer road traffic and most likely will continue to do so. Hence immediate policy interventions are not foreseen in this respect.

Road maintenance is one of the key issues in the short term that will have an impact in extreme weather situations. Both proactive maintenance and fast-reacting operations are called for, especially in cases of snow storms, heavy precipitation resulted breakdowns of infrastructure and clearance of road paths after severe storms. The safety impacts of enhanced maintenance are limited, but time cost reductions can be significant. For publicly owned roads, the costs of enhanced maintenance fall upon the public sector, i.e. the states, cities and municipalities.

Railways, the most modern ones at least, are also loaded with high-end safety technologies and systems that will continue to work for the benefit of safe rail system. The safety record is already good for railways, and the likely improvements can be expected when out-dated systems are modernised on a wider scale. Again, the time reliability will continue to be an issue and here is where maintenance again plays a key role. Fast recovery times are of particular relevance for railway system and hence the emphasis on fast-reacting maintenance seems like a natural choice, not to underestimate proactive maintenance operations. Infrastructure owners, i.e. the states in most cases, bear the most of the maintenance costs.

For aviation, the continuity of airport operations is perhaps the most pressing issue. Availability of runways and fast deicing of aircrafts seem to be measures that in many cases dictate the continuum of transport operations, when responsive actions in general do matter. In some cases, such as thunder storms and extreme winds, there is very little that can be done on the spot. For these types of phenomena, the responses have already taken place when devising strategies to adapt to such phenomena. Airports, be they public or private, will assume the costs and roll them over to airline operators –and ultimately to passengers.

Inland waterways' biggest challenge also relates to time costs and some infrastructure related issues. However, there are in practice not too many clear action options within the vicinity, as the phenomena are of such nature, that their control is extremely difficult. For drought periods or too high water levels little can be done. Formation of ice cover is also among the list of harmful phenomena, and there the possibilities lie in two directions: either the operators change their fleet so that it can manoeuvre in icy conditions or that some arrangements are made for ice-breaking assistance. The former costs obviously fall on operators, whereas the latter option can be arranged in different ways. Ice-breaking services could be publicly managed and offered free of charge, or the operators could be obliged to pay for such services.

For maritime transport, especially for shorter distances in the Baltic Sea, Mediterranean, North Sea and Black Sea the vulnerability spot is almost always in ports. Hence the port owners, be they public or private, will have to assume the responsibility on the continuation of port operations also in more extreme conditions. When storms are truly severe, little can be done to continue port operations and in such cases the operations make little sense anyway. Other phenomena, such as snow can be combatted more easily.

The below table attempts to identify on which costs it is possible to influence and who seem to be the first-in-line responsible in assuming the costs. Also the foreseen rolling over of the costs is described since many of the chains of rolling over are quite obvious.

Table 44. Cost items, and the first-in-line to combat the associated costs by adverse weather.

Mode	**Costs items**		
	Infrastructure	*Accidents*	*Time*
Road	Infrastructure managers, costs rolled over to tax payers	Automotive industry through technology improvements, costs covered by customers	Infrastructure managers can adopt proactive and fast-response maintenance strategies
Rail	Infrastructure managers, costs rolled over to operators => railway passenger and freight customers	Railway systems suppliers and equipment manufacturers, ultimately the operators and their clients	Infrastructure managers can reduce these costs by proactive and fast-response maintenance
IWT	Infrastructure managers	🟩	Operators can improve their fleet and pay for e.g. ice-breaking assistance or
Short sea	Port owners	🟩	Port owners can prepare for extreme events and improve maintenance especially in the Baltic Sea for winter times
Aviation	Airport owners/operators	🟩	Airport operators and owners can improve the infrastructure availability by having more capacity to clean runways, have extra runways and prepare for

	🟩	🟩	🟥 fast-response actions in case of extreme weather; these costs are inevitably rolled over to airline operators and passengers
Non-motorised transport	🟩	🟥 Cities and municipalities and in some countries property owners are responsible for taking care of pedestrian and bicycle pathways and sidewalks	

Legend: green = non-significant costs, yellow = somewhat significant costs, red = significant cost, white = uncertain

5.4 Policy recommendations – first thoughts

The EU policy options seem to point to the direction of infrastructure management, especially when it comes to ensuring the operability of networks. In the short-term, the obvious emphasis will be on maintenance strategies and preparedness for quick responses. For all phenomena, these strategies do not always work.

Some industries are already well on the way of providing safer systems. All modes' vehicle and fleet manufacturers have shown already by now an impressive track record in safety improvements. By bringing in some technologies especially useful for extreme / adverse weather conditions, the trend will continue. Some technologies are evident, and supporting the deployment of these will also improve weather resilience of the transport system as a whole:

- road vehicles and systems: anti-skid, lane-keeping, collision warning, collision avoidance, obstacle recognition;
- rail equipment and systems: safety sub-infrastructures, advanced train control systems, cooling / heating of critical vehicle parts
- aviation: more advanced flight control systems, more reliable aircraft;
- inland waterways and short sea: advanced vessel traffic service systems (vessel traffic management).

The safety systems and technologies are well established and there is a good culture in endorsing them. The efforts to take these further should be nourished through rtd-programmes, tax benefits (if feasible), and prioritization in action programmes of industries and public sector actors.

However, the time costs, which seem to be on the rise, are not considered directly to be anybody's business. The European freight industry and supply chains are suffering from severe time-related costs, as well as the European passengers. When infrastructure fails to deliver reliability and resilience, the costs are absorbed by users of infrastructures and transport system end users. Enhanced maintenance able to improve the situation is on the responsibility of infrastructure managers and owners, but their efforts are – particularly and increasingly, nowadays – dictated by strict cost control with little room for considering the time costs of transport system clients. The present gap between management practices and true needs is calling for new maintenance management concepts and metrics. Successful infrastructure maintenance should measure the availability and reliability of the infrastructure in order to demonstrate short-term performance. Such performance indicators could include, for example:

- % of availability per vehicle – this is already used in railways and aviation, but not for road network
- cost of maintenance / availability unit – this type of indicator could assist in selecting efficient maintenance strategies and measures
- number of reliability or availability breakdowns per traffic volume unit
- ex post evaluation of major incidents resulting in time costs – this would highlight the impact of reliability and availability meltdowns.

The policy option would naturally be to establish such performance targets for infrastructures and their management.

Long-term performance calls for more advanced asset management systems and criticality evaluation of nodes, links and parts of networks. There are many ways of doing this, none of them probably exhaustive and each having their pros and cons. One of the obvious first indicators for criticality or vulnerability is the sheer volumes of passengers and freight. These indicators alone do the majority of the prioritization since they are concentrated around large urban and industrial centres. But here might be other network criticality indicators, such as the exclusiveness of links and access points and criticality of societal functions: an access road to fire department, hospital or military base; a rail link to harbour or industrial plant; airport access links; etc.

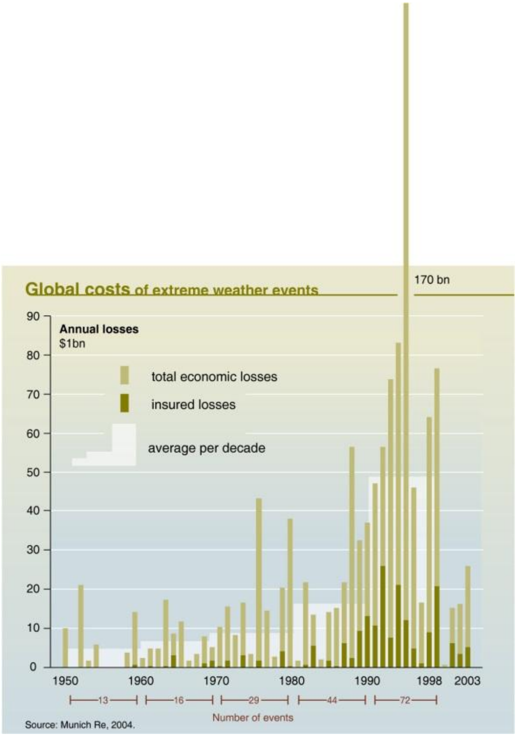
Criticality assessments should be done at all levels – regions, countries, cities – and for all transport infrastructures.

But transport networks alone are not sufficient. There are also supporting infrastructures that might be even more critical, such as energy and communications networks. If these fail, they will then have an impact on transport systems’ operability. Electrified railway systems and communications -reliant aviation systems are highly dependent on other utility networks which could deserve first priority over transport networks. There is a definite need to view our infrastructures and networks form a more holistic perspective than what we have done so far.

5.5 Final remarks

European Union’s 27 member states face each year at least 15 billion € cost resulted by extreme weather. This cautious estimate is about 0.1% of the EU-27 GDP, and about 30 € annual extra cost to each EU-27 citizen. However, we did not find any significant signals that these costs would significantly increase in the future, except for the time costs. But the figures are yet so profound that actions are needed. In some parts of Europe, they are probably needed more in some other parts, somewhat less. The figure we estimated could well be twice as high.

There have been estimates that extreme weather costs exceed substantially our estimates, although we included so called *high-impact* weather phenomena into our definition of *extreme weather*. One of the reasons we believe that “costs are on the rise” is simply the fact that these costs have received our full attention and it is in the “insurance list” of both insurers and their clients.



Source: Munich Re, 2004.

Figure 14. Global costs of extreme weather until 2004. (Source: MunicRe)

These costs are nevertheless real and always borne by somebody. The question really is how we want to even the costs and how can we reduce them. This analysis at hands gives a positive signal: unless our climate is radically changing towards more extreme events, the costs can be handled and even reduced quite efficiently provided that the necessary will and actions are there. It is of course also possible that our climate is radically changing and this means that our calculations might not hold in the future decades to come.

One relevant feature we need to keep in mind is the uncertainty of these costs, which mostly result in from the uncertainties related to weather extremes and their probabilities. Using uncertainty as an excuse to hold up decisions or actions is in fact accepting an equal risk: nothing points to the direction that present status quo is any less uncertain than the envisioned changes.

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Title	**The costs of extreme weather for the European transport system.** EWENT project D4
Author	Marko Nokkala, Pekka Leviäkangas and Kalle Oiva (editors)
Abstract	Extreme weather causes damages to the transport system worth billions of euros annually at the European level. This report presents results of a first attempt to have the full picture of various impacts across transport modes and with Europe-wide coverage as a result of the EWENT project. These impacts are mainly created by accident costs and delays and cancellations as a result of the extreme weather. The single biggest contributor is the road transport, where accidents due to bad weather result to large number of fatalities and injuries. Similarly, in aviation the cancellations and delays contribute to large costs both to travellers as well as operators. There are several uncertainties involved in the calculations provided, which are results of poor data availability and assumptions made regarding the share of weather-related accidents in total accidents. However, based on the results it is clear that extreme weather events do create of variety of negative impacts, for which no solutions exist at present. The study has also analysed the trends in impacts between present and 2040 and 2070. Results show that the overall impact will be reduced by one-third compared to current situation, but this is mainly due to the fact that accidents in roads will decline due to vehicle technologies. Additional decline will be achieved through reduction in number of days with bad weather.
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Nimeke	**Yhteenvetoraportti sään ääri-ilmiöiden aiheuttamista kustannuksista Euroopan liikennejärjestelmälle**
Tekijä(t)	Marko Nokkala, Pekka Leviäkangas & Kalle Oiva (toim.)
Tiivistelmä	Äärisääilmiöt aiheuttavat monenlaisia vaikutuksia eurooppalaiseen liikennejärjestelmään. Kaikki liikennemuodot huomioon ottaen näiden vaikutusten vuosittainen kustannus on useita miljardeja euroja. Suurimmat kustannukset syntyvät onnettomuuskustannuksista, erityisesti tieliikenteessä sekä viivästymisistä ja peruutuksista erityisesti ilmailuliikenteessä. Tämä tutkimus edustaa ensimmäistä kokonaisvaltaista yritystä arvioida vaikutuksia kokonaisuustena EU:n tasolla ja esittelee EWENT-projektin tulokset näistä vaikutuksista. Suurin yksittäinen erä kustannuksilla mitattuna ovat tieliikenteen onnettomuuskustannukset. Myös ilmailuliikenteen viivästymiset ja peruutukset aiheuttavat sekä operaattoreille että matkustajille merkittäviä kustannuksia. Haasteina ovat olleet tiedon saatavuus sekä äärisääilmiöistä johtuvien vaikutusten osuuksien arvioiminen kokonaistilastoista, koska tätä tietoa ei ole erityisesti aiemmin kerätty. Tutkimuksessa tarkasteltiin myös vaikutusten muutoksia nykytilan ja vuosien 2040 ja 2070 välillä. Kustannusten kokonaistaso tulee putoamaan noin kolmanneksella (15 miljardista 10 miljardiin), mutta ensisijaisesti tähän vaikuttaa tieliikenteen ajoneuvoteknologian kehitys ja toisaalta myös äärisääilmiöpäivien väheneminen ilmastonmuutoksen myötä.
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