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# IMPROVING RESILIENCE OF EUROPEAN TRANSPORT NETWORK TO NATURAL DISASTERS AND EXTREME WEATHER: CROSS-MODAL AND MODE-SPECIFIC METHODS

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# IMPROVING RESILIENCE OF EUROPEAN TRANSPORT NETWORK TO NATURAL DISASTERS AND EXTREME WEATHER: CROSS-MODAL AND MODE-SPECIFIC METHODS

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## ABSTRACT

Natural disasters and their impact on transport networks in Europe have gained increasing attention in Europe in the recent years, following the impacts of heavy snowfall in the UK and Central Europe and the volcanic ash cloud of Iceland in 2010. So far research addressing the interaction between nature and transport networks has been limited, thus providing very limited insights to the magnitude of such impacts or how to mitigate them in the future. This paper presents one approach to address these issues, utilizing data and findings from the recent European Union FP7 projects EWENT and WEATHER.

In addition to provision of monetary valuation of costs, the data available allows to consider both cross-modal improvements in resilience and well as measures within a specific transport mode. All modes of transport were assessed (road, rail, aviation and waterborne transport) for both freight and passenger transport. Methods to better use weather data in decision-making and traffic management were also investigated.

Findings show that improved resilience can save billions of euros annually at the European level for society and transport operators. At the same, improving passengers access to information and increased cooperation between operators of various mode-specific transport networks could result in major gains in avoiding the negative impacts of natural disasters and extreme weather.

*Keywords: transport system, extreme weather, resilience, accident and time costs, cross-modality*

# INTRODUCTION

Natural disasters and extreme weather pose a challenge to transport service providers. Storms, tsunamis, fog, flooding, volcanic ash and earthquakes make local and global headlines on frequent basis. What is less discussed is how the negative impacts of these events could be mitigated in the case of future occurrence. Usually the reason for this is the lack of funding to make fundamental improvements to existing infrastructure. In the light of recent studies with Europe-wide coverage it may well be the case that pennies saved on necessary upgradings may be euros spent on fixing the subsequent damages from the reoccurrence of natural disasters or extreme weather.

Naturally, extreme weather is easier to cope with than natural disasters. Whilst both have a sudden impact on the transport system, extreme weather usually means that a certain threshold of a weather phenomenon typical for the region has been surpassed. Typical situations are intense fog, heavy snowfall or extreme cold spells or heat waves. Normally such conditions last for a certain period and the impact is mainly observed during the occurrence, with some maintenance work required afterwards. Natural disasters are more tricky as they occur with more long-lasting impacts, for instance on infrastructure and built environment. However, in most cases given the location of the incidence it is possible to identify the potential disasters typical for the specific location. Emphasis on this paper is on extreme weather, as it is more frequent and easier to categorize for the characteristics and impacts than natural disasters – it is also more easily managed in terms of mitigation and adaptation.

This paper utilizes data and findings from the recent European Union FP7 projects EWENT and WEATHER and the latest state-of-the-art findings from the on-going MOWE-IT project. In addition to provision of monetary valuation of costs, the data available allows to consider both cross-modal improvements in resilience and well as measures within a specific transport mode. All modes of transport were assessed (road, rail, aviation and waterborne transport) for both freight and passenger transport. Methods to better use weather data in decision-making and traffic management were also investigated.

The organization of the paper is as follows. In the next section the data and methodology used to produce climate change scenarios and costs of weather events is presented. Following this, we present a holistic view of weather challenges faced by Europe at present and in the future (2040 and 2070). Then the following section shows the estimates of costs of extreme weather to the transport system at present in the future. Then, we use this information to analyze potential solutions by transport mode for the key phenomena impacting the specific mode. In addition, as a novel approach we also introduce potential for cross-modality solutions for the problems faced by different modes. The final section concludes from the research.

# WHAT DOES LITERATURE TELLS US ABOUT EXTREME WEATHER AND THE IMPACT ON TRANSPORT SYSTEM?

Current knowledge on the impacts of extreme weather on is based on recent research agenda that is still very much evolving. This is also shown by the availability of data, or rather the gaps in data available. Most of the relevant studies have been carried out in the last decade, indicating that there is significant field of research left.

In the recent comprehensive study of UK transport system and climate change (Thornes et al. 2012, 29) the key impacts on transport system can be identified as:

- Storm-related direct damage to transport infrastructure and the associated disruption of service;
- Storm-related direct disruption to all transport modes through precautionary closures of services or potential catastrophic damage for instance resulting from accidents;
- Indirect disruptions from gradual climate change

Despite the fact that the example cited above discusses only the storm and its impacts, the study itself has gone through a broad range of weather phenomena, as was done in the EWENT project (http://ewent.vtt.fi/) as well and the impacts were considered on infrastructure, vehicles, resources and staff and passengers.

Sector-specific studies have also emerged, such as "Adaptation of Railway Industry to Climate Change" (Nolte 2010) and study on maritime transport operators' climate change strategy in Finland (Merenkulkulaitos 2009). Such studies have helped the decision-makers within a particular sector to address the challenges but they work in isolation of consideration of impacts of same changes to other modes of transport. Other railway focused studies include e.g. Andrey and Mills, 2003, Rossetti, 2002, and Dobney et al., 2010.

In one of the early academic works on the subject, Cools et al. (2009) assessed the impact of weather on traffic in Belgium. Not surprisingly, their findings state that "Bad weather conditions such as precipitation, cloudiness and wind speed are negatively correlated with traffic intensity, while good weather conditions such as temperature and sunshine duration are positively correlated" (ibid., p.64). They also find that according to their data elasticity of leisure travel to extreme weather conditions is greater than that of commuter traffic. This means that those who need to travel for the purposes of work have no other option but to travel even when facing adverse consequences of extreme weather.

A substantial review of literature exists concerning the impacts of extreme weather on transport. Impacts on road safety, for example, are considerable (Ashley and Black, 2008; Rauhala and Juga, 2010; Andrey et al., 2003; Keay and Simmonds, 2006, 2005; Rowland et al., 2007; Juga and Hippi, 2009). According to literature base, practically all types of weather phenomena can contribute to increased accident risk.

# DATA AND METHODOLOGY

The data used in the analyses is divided into weather-related and transport related. To start with, the calculation of probabilities and frequencies of adverse weather phenomena utilized the two datasets, ERA-40 and ERA-Interim, which cover the period of 1957-2002 and from 1989 to present day, respectively, as follows (Vajda et al. 2011):

- 2-m daily mean temperature values from E-OBS data set for cold spell
- 2-m daily maximum temperature values from E-OBS data set for heat wave
- total daily precipitation from E-OBS data set for heavy rainfall
- 2-m daily mean temperature and total daily precipitation from E-OBS data set for snowfall calculation
- 6-hour forecasted 10 m/s wind gust available from ERA-Interim dataset for wind gust
- 6-hour forecasted 10 m/s wind gust and precipitation sum, 6-hour reanalysed 2-m mean temperature from ERA-Interim dataset for calculation of blizzard frequency.

For transport sector, various data sources were used. Aviation industry has good datasets available and also industry values for passengers' time costs. For accidents on roads EU statistics were used, for rail and maritime accidents respective industry data were utilized. For time costs on freight, specific studies were analyzed to provide some industry estimates on magnitude of delays and their associated costs. For road and rail transport, time costs and valuation of accidents (statistical value of life, severe and slight injuries) were collected from those countries where figures were available. European average figures were determined from figures available and complemented with the use of detailed data for regional level analyses. (Nokkala et al. 2012).

Methodologically, for weather the main phenomena were analyzed and projections of their future occurrence were produced. Similarly, the accidents data were adapted to future using trends observed in other studies. For time costs, using data on commuters in Helsinki a model to calculate per passenger costs at annual level was created. The model was used to calculate impacts on passengers in major cities for commuter traffic for road and rail. For aviation, calculations for operator costs and passengers' time costs we carried out using industry data on traffic on several European airports, which cover 80 per cent of daily movements. Using data separated into wide-body and narrow-body aircrafts it was possible to get accurate daily passengers volumes and estimate the impacts based on number of bad weather days observed at these airports.

Finally, sensitivity analyses were carried out, for accidents data this was done using various assumptions on the amount of accidents resulting from extreme weather data, as no statistically significant sample of accidents existed that would cover the volume of accidents which were weather-related. Similarly, for aviation industry operator costs various percentages of flight cancellations were used for sensitivity analyses, as well different average delays for passengers, measured as minutes of average delay for total number of passengers on a given day with reported extreme weather conditions.

# WEATHER CHALLENGES TO TRANSPORT SYSTEM – RESILIENCE CHALLENGE NOW AND IN THE FUTURE

Each transport mode is affected by different types of extreme weather events. The starting point for the analytical work is to establish the types of extreme weather events, which have an impact on certain modes of transport, and the thresholds, which start to impact the operations of that particular transport mode. In the EWENT project, significant efforts were directed towards the prediction of future weather conditions in 2040 and 2070 (Vajda et al. 2011). This work was done at such a level of detail that further work on climate zone level (Mediterranean, Northern Europe, Central Europe, Maritime and Alpine) was possible to carry out on the consequences of the events. European scale presentation of maps for events was created and the thresholds of events with respect to transport modes were defined.

By thresholds the EWENT project and this paper will refer to a level of phenomenon that will trigger a change in the consequence of the event to transport user and operator. For instance, in terms of temperature 0 degrees and below triggers icing, posing a specific challenge to several transport modes. Similarly for wind and other phenomena, the various thresholds create a number of different consequences. In the EWENT project reaching and exceeding certain thresholds, for some transport modes more than one with different triggering impacts, were considered extreme weather and based on the frequency financial implications were calculated. These will be presented in the following chapter. At the same time, WEATHER project (Enei et al. 2011) also provided figures of impacts of extreme weather events, but particularly for road transport the figures were lower than those obtained in the EWENT project. The most probable cause for the differences in these two estimates is the definition of extreme weather event and also the associated probability of accidents resulting from these events. Data availability was one major factor for uncertainties in estimation of impacts in both projects, as well as differences in chosen pricing principles.

Looking forward to future impacts, first reason why the climate change matters to transport system is that the service providers and users like to be informed of the requirements of operability of the system in the future. It has become evident that even at present the operators and regulators in Europe, including the European Union itself, do not know the true cost of occurrence of extreme weather events to the transport system as a whole. For policy-making this matters, as any adaptation or mitigation measures based on true impacts is lacking at present (see e.g. Leviäkangas et al. 2012).

Second reason is that in terms of planning new infrastructure in the future realizing and mapping the occurrence of extreme weather can help to design new projects with better resilience. This refers to impacts of flooding and fog for instance, which can be cost factors to infrastructure operators and service users in terms of time costs of delays etc. The forecasts provided in the EWENT project did not directly address the future occurrence of fog or poor visibility so there are still existing uncertainties underlying the current knowledge of extreme weather event in the future.

Table 1. Changes in extreme weather conditions between present and 2040 and 2070.
(Source: Bläsche et al. 2011)

| Forecast per region | | Nordic | | Temperate | | Alpine | | Mediterranean | | Maritime | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011-2040 | 2041-2070 | 2011-2040 | 2041-2070 | 2011-2040 | 2041-2070 | 2011-2040 | 2041-2070 | 2011-2040 | 2041-2070 |
| Wind gusts | | -1,5% to 0,3% | -2,1% to -0,2% | -0,4% to 1,5% | -1,3% to 0,5% | -1,1% to 0,8% | -5,8% to 0,3% | -0,6% to 2,5% | -2,3% to 4,1% | -0,5% to 1,6% | -3,1% to -0,9% |
| Snowfall | | -7,7% to -2,6% | -14,2% to -7,2% | -3,1% to -0,8% | -7,4% to -1,2% | -4,5% to -0,9% | -9,6% to -1,3% | -2,0% to 0% | -3,5% to 0% | -2,9% to -0,2% | -3,9% to -0,3% |
| Heat Waves | | 0% to 4,0% | 0,1% to 6,5% | 0,1% to 7,0% | 2,8% to 18% | 6,2% to 14,6% | 15,8% to 28,4% | 12,7% to 29,1% | 24,6% to 41% | 0,1% to 2,8% | 0,2% to 7,6% |
| Cold Waves | | -16% to -7,8% | -41% to -22% | -8,8% to -0,5% | -25% to -5,3% | -15% to -5,1% | -29% to -12% | -8,1% to 0,5% | -18% to 0% | -7% to -3,5% | -14% to -1,5% |
| Road | Delay | > | > | > | > | > | > | > | > | > | > |
| | Acc. | < | << | < | << | < | << | < | << | < | << |
| Rail | Delay | <> | <> | <> | <> | <> | <> | <> | <> | <> | <> |
| | Acc. | < | < | < | < | < | < | < | < | < | < |
| Aviation | Delay | ≤ | << | ≤ | ≤ | ≤ | ≤ | <> | <> | <> | ≤ |
| | Acc. | = | = | = | = | = | = | = | = | = | = |
| Inland waterways | Delay | < | << | = | > | < | ≤ | > | >> | N/A | N/A |
| | Acc. | = | = | = | = | = | = | = | = | = | = |
| Maritime | Delay | < | < | = | = | N/A | N/A | = | = | < | < |
| | Acc. | = | = | = | = | = | = | = | = | = | = |
| Symbols: = no change, ≥ possible increase, > increase, >> significant increase, ≤ possible decrease, < decrease, << significant decrease, <> mixed signals, N/A not assessable | | | | | | | | | | | |

Looking at the changes by climate zones, it is clear to see that the global warming as a symptom of the climate change reduces the occurrence of cold waves and snowfall in the future. On the other hand, this leads to increase in heat waves and this will have impact on rail maintenance, drivers fatigue etc. which can become more pressing problems in the future than at present. Heat waves may also have yet unforeseeable impacts. The above table shows the foreseen impacts on different transport modes in terms of accidents and delays. Overall, the significant impacts observed are related to reduction in road transport accidents, which also shows in the following chapter in terms of future costs of extreme weather. However, delays in road transport are likely to become more frequent and the associated time costs will rise.

# COST OF EXTREME WEATHER TO TRANSPORT SYSTEM

Current cost levels of impacts of extreme weather were estimated in the two European Union FP-7 projects already referred to, EWENT and WEATHER. As mentioned earlier, the results were somewhat different from one another, for instance due to the definition of extreme weather phenomena (with regards to the threshold values) and the associated incidence of accidents resulting from these.

Table 2. Extreme weather resulted costs for the European transport system at present.
(Source: Nokkala et al. 2012)

| 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. So the less hard winter with lower temperatures can increase the associated risk of accidents compared to cold and snowy conditions. 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.

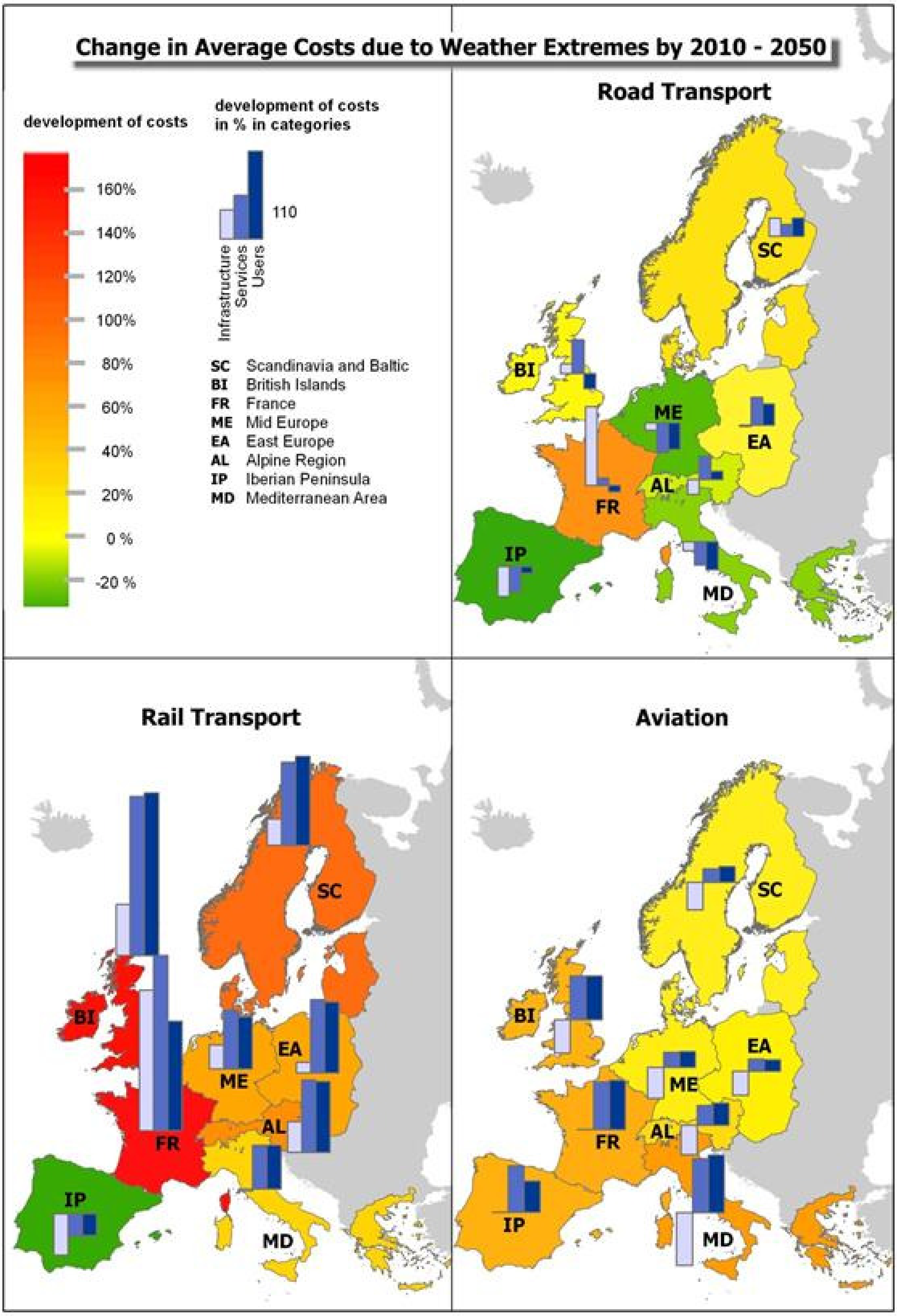
Table 1. Future costs (present price level, ca. 2010) of extreme weather resulted consequences to European transport system.
(Source: Nokkala et al. 2012)

| 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 winter maintenance | **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 of Europe's declining population. Urbanisation can reduce the impacts on long-haul and commuting travel, if more people will live in larger urban settlements in the future. Nonetheless, urban transport will become ever more critical.

The change in costs between present and 2050 is shown in Figure 1 below. As can be seen, the major impact that will be observed is the costs increasing in rail transport in the future, where all regions with the exception of Spain and Portugal experience an increase in costs, which is particularly large in the British Isles, France and Scandinavia.

Figure 1. Change in average costs due to weather extremes from 2010 to 2050. (Enei et al. 2011)



From the identification of regional impacts and costs it is possible to move to analysing the solutions for improvement of resilience. There are certain measures that can be implemented in the immediate future and some which will require more time and financial resources. This mapping of alternative solutions is done both from the mode-specific starting point and the cross-modality perspective in the following chapter.

# WAYS TO IMPROVE RESILIENCE – SHORT TERM AND LONG TERM SOLUTIONS

## Mode-specific resilience issues

In approaching the mode-specific issues of improved resilience, three factors are important to consider: Infrastructure costs, accident costs and time costs. In the analyses to follow, we have tried to assign each of these cost categories a price tag, even if a relative one. The interesting fact that the table shows is that those big-ticket cost items, time costs on road, rail and aviation transport would also have biggest gains in terms of reduction of negative impacts. This is similar for accidents in the road transport. This suggests that measures to improve the resilience in these areas should be subject to rigorous and in-depth cost-benefit analysis from the perspective of impacts also extending across the national boundaries.

Table 2. Cost items, and the first-in-line to combat the associated costs by adverse weather (Source; Molarius et al. 2012)

| **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 manage extreme weather risks through insurance and freight contracts |
| *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

From the framework above, some mode-specific recommendations how to improve short-term and long-term resilience can be put forward. These are listed for some selected phenomena in the table below. More detailed analyses will be carried out in the on-going MOWE-IT project.

Table 5. Selected weather phenomena and some ways to mitigate their impact in short and long term.

| Transport mode | Weather phenomena | Short-term | Long-term | Feasibility (costs) |
|---|---|---|---|---|
| Road | Wind gusts | Improve road-side information areas of strong winds | Design shields at critical areas to prevent wind for disturbing traffic | Location-specific, in areas with high occurrence most likely high costs as well |
| | Low temperatures | Improve road-side information and use variable speed limits | Design new ways to reduce impacts (vehicle technologies, maintenance equipment etc.) | Short-term relatively low cost, long-term high cost |
| Rail | Wind gusts | Improve information systems to alert of incidents or damage to infrastructure; clearing of vegetation (trees) in rail corridors | Design new routes with resilience to wind gusts; investigate possibilities for sub-surface electricity and communications systems | Some are relatively low cost measures, easily to adopt, some require substantial investments |
| | Low temperatures | Increase maintenance staff at critical times; equip switches with efficient heating systems | Design equipment and maintenance with better resilience against cold temperatures | Depending on frequency and development needs costs can be minor or more significant |
| Aviation | Fog (visibility) | Improve forecasts on conditions resulting in poor visibility | Design and locate new airports in ways to reduce fog | Significant but related to building of the entire infrastructure |
| | Low temperatures | Improve de-icing operations and maintenance at vulnerable airports | Improve equipment that can faster and cost-effectively provide needed maintenance | Compared to problems the costs of technologies are relatively low |
| Waterborne transport | Wind gusts | Improve weather information provision | Design port entrances and handling equipment with better resilience against wind | Relatively low costs |
| | Drought | Provide information to ships in advance | Design inland waterways with greater resilience to drought, including ports | Relatively low costs |

These examples provided show that there are many ways in which improvements can be achieved in terms of improved resilience. Particularly in the short-term many actions would require a change in the mindset of service providers, as the measures are relatively low-cost and related to use and utilization of information in many cases. In this respect, the questions of what information is available and how it should be used become relevant.

## Cross-modality resilience issues

Cross-modality in transport system is a new area for research. What we refer to as cross-modality in the context of this paper is the opportunity to reroute or alter transport patterns of goods and people, when deemed necessary. Cross-modality will have several areas of study that are important in defining what the case by case opportunities available for substitution are. These areas are:

- Legislation on passenger rights;
- Collaboration between transport authorities from different countries and transport modes;
- Collaboration between transport operators representing different transport modes;
- Costs and time associated with alternative travel options

Legislation in Europe on passenger rights for certain transport modes at present entitles passengers for compensation in the case of delays and cancellations (European Commission 2011a, 2011b). However, force majeure circumstances are usually outside the scope of the legislation. It would be advisable; that when information on the substitutability becomes available at the European level the legislation would suggest that in the case of certain identified events operators would have the choice of proposing alternatives to original travel. By providing such alternatives operators would be free of obligations to provide financial compensation. This could be considered in the passenger compensation schemes.

Collaboration of authorities can be important in facilitating the service providers to offer a better choice in the case of extreme weather events and natural disasters. Plans to cooperate across national borders and with other transport modes should be drawn and in the case of realization of the event the coordination of activities should be mandated to a lead authority. This could be defined by the transport mode(s) affected by the phenomena in question.

The key challenge is the cooperation between operators, within transport mode and across different modes and infrastructures. At the European level this requires greater coordination as national boundaries do not limit the impact of weather events. In this sense, information of delays on or closure of a corridor or a node should be communicated to other operators so that the response can be planned. As an example, closure of an airport, which in some cases can be foreseen based on weather forecasts will result in cancellations of flights not only departing from the airport in question but also of flights destined to arrive to the airport. If closure information is not communicated to other airports in time, arrangements for alternative locations can become inconvenient and further transit of passengers will be delayed.

From the operators and passengers view point, time and costs of alternative travel options are two key determinants of considedation of mode shift. These are linked to the nature of goods and trips of passengers, which have relevance in determining the rationale to use alternative modes. In principle, for certain types of goods it is envisaged that short delays will result in wait, and for passenger transport the increased telepresence can compensate for need to travel in the case of delays.

Methodologically, the on-going MOWE-IT project will address the practical opportunities for cross-modality as a function of several factors, the interdependence of which determines the potential of applying cross-modal travel planning. These factors are:

- Estimated occurrence of the weather phenomena that prevents operations of one or more modes of transport; at present reliable weather forecasts are up to 6 days, which is considered the maximum period for analyses.
- Time of travel when shifting to alternative transport mode: Feasible distances will be mapped on the basis of the time spent using alternative mode; radius for feasible change between modes for both passenger and freight will be studied keeping in mind the maximum foreseeable duration of the event. In passenger transport, the factor of leisure or business travel has to be considered, as this will have a resistance factor related to individual’s preference to travel or to wait.
- Costs associated with the mode change: These can be lower, if the alternative mode chosen is lower costs, but usually associate with longer travel time.

What the analyses will result in is a matrix showing key European transport corridors and nodes for both passenger and freight transport, with the above mentioned data showing the alternatives available for cross-modality. This, complemented with recommended alternatives shown and visualized in maps will provide decision-makers, operators and passengers information on cross-modal substitution opportunities available. The results will also show when waiting is the best opportunity in terms of costs or duration of the alternative choices available.

Naturally, the data can be used to analyze other types of interruptions as well, which can be related to natural disasters, terrorism or periodic maintenance of the network. Informed operators and travelers can better improve the resilience of transport system simply by making better choices regarding their transport needs.

There are also intermodal considerations as noted by Thornes et al. (2012, xiii), as they state that “There is considerable overlap between the four transport modes …, for instance road transport is fundamental to get the public and staff to airports, railway stations and ports. In difficult weather conditions, one form of transport may have to substitute for another, for example, in times of extreme flood, air transport may provide the only access into an area. If transport is disrupted, then there is a considerable cascade effect for other industrial sectors including movement of labour and materials. For example, 'just-in-time' production, where stockpiles of material are kept to a minimum, reduces any margin of flexibility if transport is disrupted". These findings will also be considered in MOWE-IT project when looking at the cross-modality alternatives available.

EWENT identified different options for strategic emphasis when considering the resilience enhancement of different networks. Some networks are more manageable than others, and some may be in fact more critical than others, but these considerations vary according to contexts, i.e. country, policy preferences, climate zone, and network characteristics.

Table 6. Strategic options for land transport network emphasis in resilience enhancement. (Leviäkangas et al. 2011).

| Strategic emphasis | Pros | Cons |
|---|---|---|
| Road system resilience | Much of the cost can be borne directly by the users, because users pay for in-vehicle safety systems and possibly also partly for information services.<br>The road system is the most "connecting" mode of transport – its reliability also serves the other modes best. | Investing in maintenance equipment and more comprehensive traffic management is expensive and possibly not a very cost-efficient strategy.<br>The road system is a scattered system that is complex to manage and control. |
| Rail and aviation system resilience | Rail and aviation systems are concentrated and centralised and manageable.<br>Mitigation and adaptation strategies are more easily implemented in centralised systems.<br>Aviation infrastructure owners and the aviation industry are obliged to bear much of the cost (which are then passed on to the consumer). | Both industries are in an economic pinch and introducing more obligations might further aggravate their situation.<br>For the rail sector some measures might require large public investments, which could be difficult to justify for a sector that already enjoys some public financial support.<br>Both rail and air travel chains almost without exception include stretches on roads and streets. |

# CONCLUSIONS

Extreme weather events in Europe will not disappear as the consequence of forecasted global warming. Some events, such as heat waves, will become more frequent as global warming increases the average temperatures between now and 2070. However, what the research shows and a reduction in total costs of the extreme weather on annual terms should be put in the context of the fact that between now and 2040 the total costs in cumulative terms will be in the magnitude of 300-400 billion euros, which suggests that the number could be significant lower if measures to improve resilience were adopted now rather than later. There is uncertainty involved in the estimation of the annual costs, so availability of better data at the European level can further improve the estimates available now. However, the two projects referred to here have clearly shown that independent of methods the annual costs at European level are billions of euros.

It should be noted that the major decline foreseen in costs of extreme weather events results from improvements in the safety features of passenger vehicles seen to take place between now and 2040. Already now several features, such as automatic collision prevention systems and in-vehicle automatic navigation systems improve the safety, but their penetration rate is still low. E-call, the standard on in-vehicle emergency system, can improve the response time in the case of accidents and will result in less severe accidents and fatalities.

The research on this matter is still on-going and by end of 2014 the data available for cross-modal substitution should be available, as the European Union FP7 funded "MOWE-IT" project will bridge the gaps in the information at present. At present the challenge is well described in Thornes et al. (2012, 28) as they conclude "to calculate the scale of climate change risks on transportation, a number of assumptions need to be made to take into account socio-economic scenarios and technological change. It would be advantageous to develop a holistic framework to take these non-physical elements into account instead of just purely looking at the climate response of the sector. However, this remains a significant gap in current research". What we can conclude is that there is a lot of information available regarding the weather phenomena occurrence now and in the future and most of the cost items are known as well. What seem to be lacking as well are detailed plans from authorities regarding the planned measures to address the mitigation challenge. This problem is likely to persist as the coordination of measures is within national authorities' jurisdiction and most problems are not country but region specific. More importantly, opportunities to improve the cross-modality possibilities are limited by lack of appropriate coordination mechanisms.

One way to address the issues regarding passenger transport would be to provide in the passenger's rights regulations opportunities for operators and service providers to avoid extra payments if they have informed passengers of potential delays and cancellations and provided alternative travel suggestions, Again, this would require such a mechanism for information sharing and management that does not exist at present. Given the relative frequency of the events described there might be great benefits from creating such a system.

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