Identifying the need for an integrated framework for linking climate change impacts to emergency adaptation strategies for applications on transport networks

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Introduction - Motivation

- Growing interest in studying the impacts of climate change on transport networks
- Transport is an important/critical part of economic activities
- Research gap: Lack of an integrated approach that can link problem parameters with solutions
- Goal: Identification of optimal adaptation measures that minimize losses

Previous work

- EU level:
  - White Paper “Adapting to climate change: Towards a European framework for action”, 2009
    - “Adapting Climate Change and Water, Coasts and Marine Issues”
    - “Impact assessment”
  - Alcamo et al. vulnerability definition: “the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes” or “the function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity”, 2007
  - OECD, 2008
- USA:
  - Committee on Climate Change and U.S. Transportation of the Transportation Research Board, 2008

Previous work

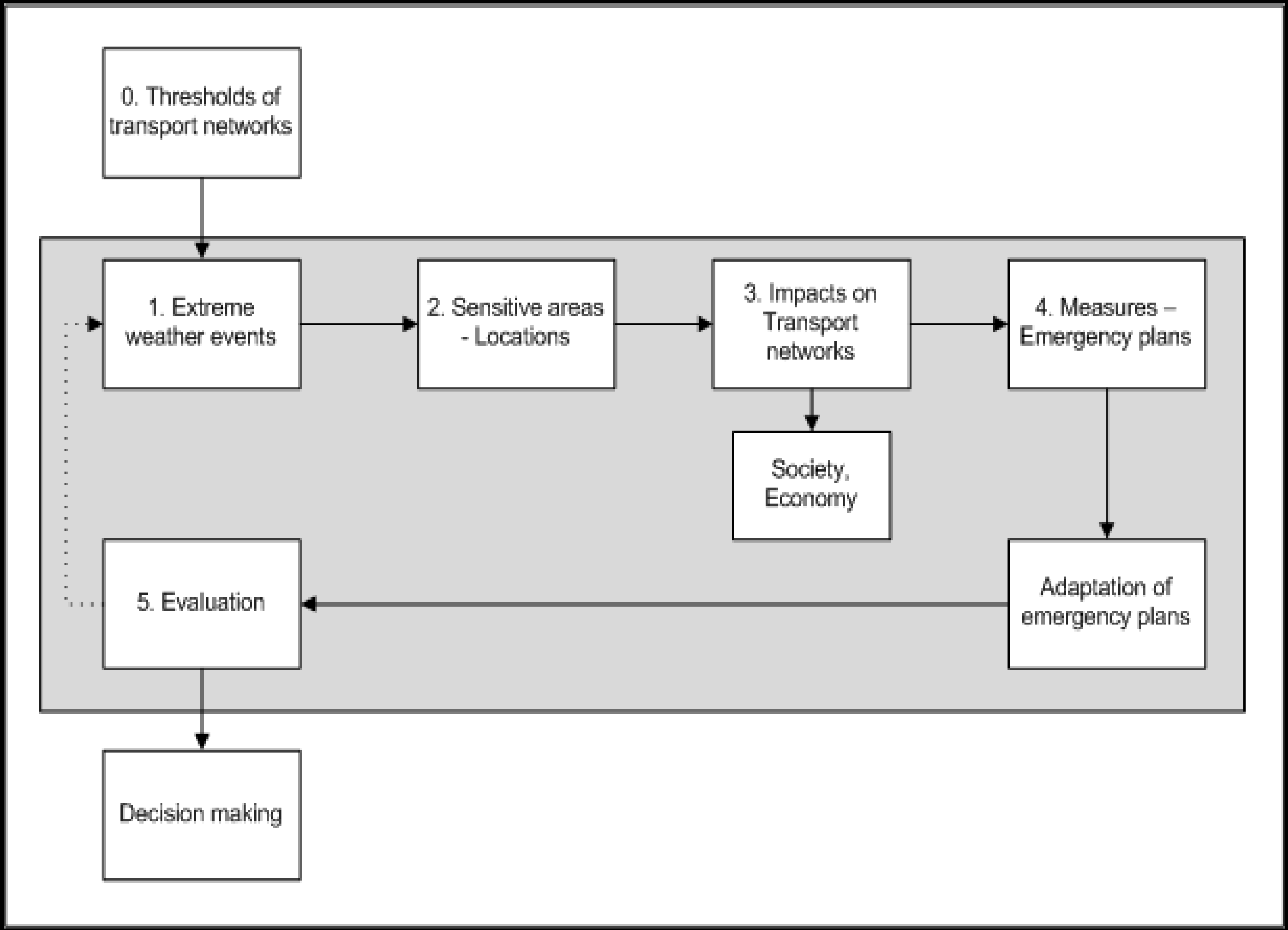
- Performance of transport networks and criticality of network components:
  - Taylor and D'Este, 2007
  - Kim and Lee, 2006
  - Nagurney and Qiang, 2009
  - Schulz, 2007
- Impact assessment of climate change and extreme events on transport networks:
  - Eichhorst, 2009
  - Suarez et al., 2005
  - Koetse and Rietveld, 2009
- Emergency management:
  - Emergency Management Australia Report, 2004
  - US Federal Emergency Management Agency, 2007
- Integrated methods
  - Jaroszweski, Chapman and Petts, 2010

Foreword of the sequential concept for determining the optimal strategies

The multidimensional character of the problem

- "Which are the optimal adaptation measures' combinations for achieving the maximum reductions (cost savings) of anticipated future losses on transport networks (and consequently to society) due to climate change?"
  - Which are the most severe extreme events that are likely to happen? (Event with associated probability)
  - Where will these events take place? (Location and geographic extent)
  - Which are the transport networks that will be affected the most? (Network dimension)
  - Which are the measures for addressing these events?
  - Which is the optimal combination of measures that should be taken for minimizing the effects?

Foreword of the sequential concept for determining the optimal strategies



Foreword of the sequential concept for determining the optimal strategies

Setting the problem

- “For a period of the next N years (N= 30, 40 or 50 years) with an available budget B, allocate B in such a way, so as to achieve the optimal reduction of the impacts due to future extreme weather events”.
- The perspective of this approach can be understood as the one of a central government or any other organization, which seeks to allocate the available resources for covering future risks in an optimal way.
- Neither does it try to match adaptation measures to extreme events nor does it attempt to determine costs associated with certain transport modes and extreme events.
- The framework rather aims to set the problem in a realistic basis, where the first and most important step from a central perspective is to determine the priorities of investing the available resources by taking into account the impacts of all possible events, in all areas, for all transport networks and modes and finally to reduce them by selecting the adequate, optimal adaptation measures.

Foreword of the sequential concept for determining the optimal strategies

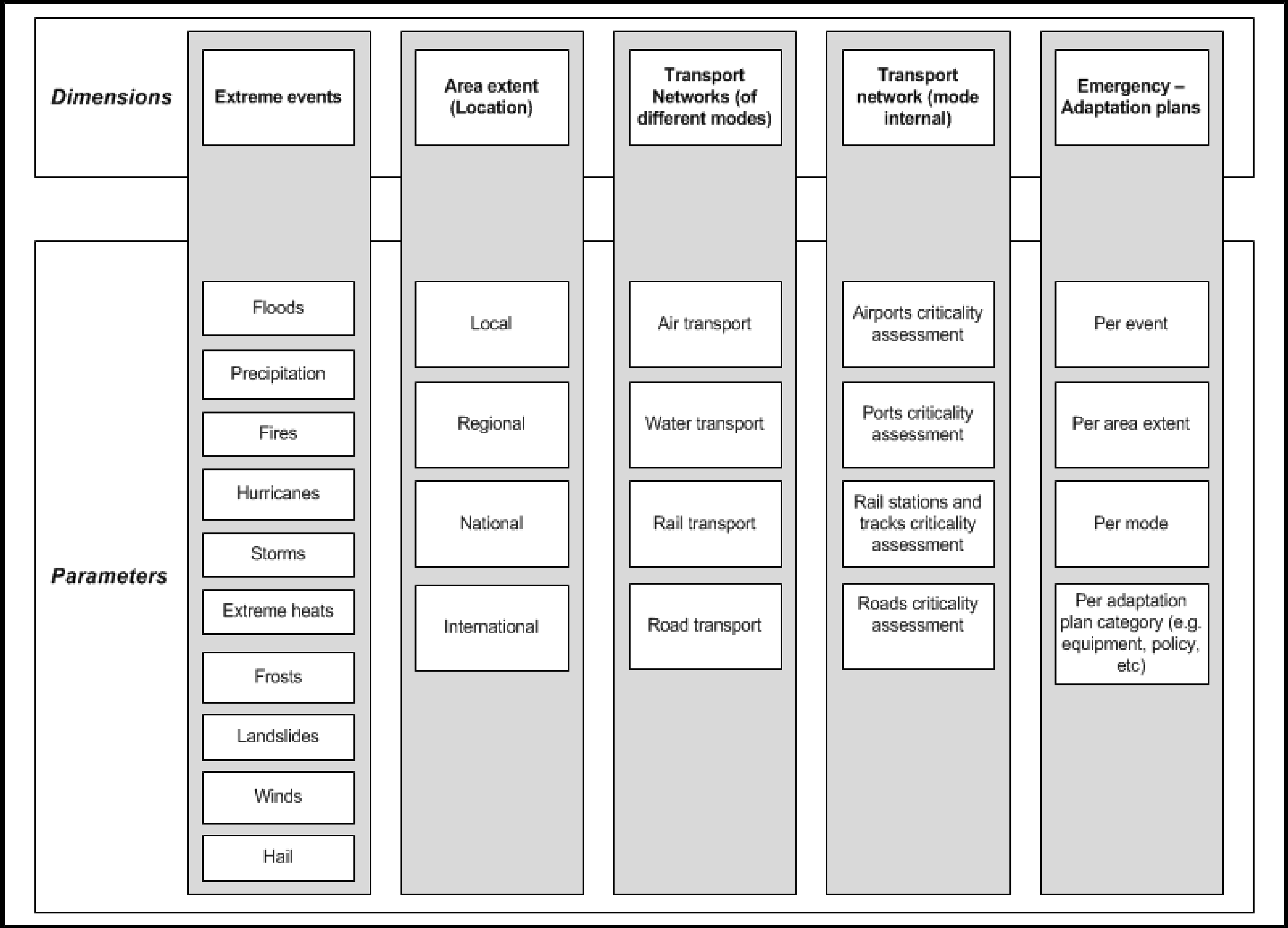
Basic definitions and assumptions

- Vulnerability of a network element: its physical sensitivity to extreme events (associated to specific thresholds of extreme events’ intensity)
- Criticality of a network element: the importance of the specific element in the network’s regular operation (associated to the entire network)

- Precondition for the application of the framework: specific thresholds for the vulnerability of transport infrastructures are determined, as trigger points of different vulnerability levels
- It is assumed that this information is known or given to the user of the proposed framework

Foreword of the sequential concept for determining the optimal strategies

Identification of the common links for the analysis



Foreword of the sequential concept for determining the optimal strategies

Identification of the common links for the analysis

- The most suitable parameter capable of providing a common classification framework is the 'Area Extent' of the extreme events
- The categories of this specific dimension (local, regional, national and international) match with all the other dimensions and furthermore provide a sound theoretical basis for examining all the other dimensions of the problem

Problem "dimension"	Link to "Area extent"
Extreme Events	Their impacts can be categorized based on the area extent that occurred
Transport Networks	The different transport modes can be considered for each specific area extent. The criticality assessment methodology can also be defined, considering different area scales.
Adaptation measures	The emergency management is classified in relation to the area extent of the events, as the corresponding public authority is in charge of the operation and has the overall responsibility. Moreover the adaptation plans follow the classification of the authority and so the classification of public authorities is based on the 'area extent' of their jurisdiction.

Description of the Framework

The “Event” dimension

- Accurate definition of the potential events during this specified period: An event is defined as any extreme weather or natural event that can cause malfunctions on transport networks (fires, floods, precipitation, hurricanes, storm surges, extreme heats, frost, landslides, wind and hail).
- In order to respond to an event in an optimal way, the exact impacts of the event must be predicted. The parameters that differentiate the impacts of an extreme weather event are:
  - The frequency of the event (referring to the potential number of times that the event will occur during the defined period of analysis)
  - The intensity of the event (referring to the way that every event is measured and the respective thresholds in relation to the transport infrastructure). As an indicative example, one could mention that extreme heats can be measured in Celsius or Fahrenheit degrees and three different categories could be 40^o-45^o, 45^o-50^o and >50^o C.

- The output of this step is the probability of each event occurring in the period of analysis P_E. The probability of each event is associated with the frequency of the event, as well as with the intensity of the event.

Description of the Framework

The "Location" dimension

- The dimension of location reveals the area in which the event both takes place and affects
  - 1: The area with impacted infrastructure (direct impacts due to the event)
  - 2: the area with impacted performance (due to diverted traffic originating from closed links - indirect impacts)
- The dimension of 'location' is defined as the area that the event causes impacts on the transport networks, resulting to any kind of infrastructure oversaturation (due to diverted traffic caused by network failures), closures, malfunctions and damages
- Local level
- Regional level
- National level
- International level

Description of the Framework

The "Network" dimension: Phase 1 Transport modes CA

- The output depends on the 'economic importance' of the respective modes for a specific area extent
- 'Economic importance' of the different transport modes is defined as the total economic production quantity that is created from the regular function of each transport infrastructure
- In order to optimally allocate a certain amount of money to different transport modes, the relative portion of the economic product of each transport mode is computed. The amount assigned to each transport mode is equal to its relative portion of the total social (economic) benefit of transport infrastructures for each area extent. Different socio-economic benefits of modes can be defined as a, b, c, d and e while the relative portion R_P per transport mode is equal to:
- $R_P = \frac{i}{\sum B = a+b+c+d+e}$ *where* i={a, b, c, d, e} and B= benefit

Description of the Framework

The "Network" dimension: Phase 2 Mode-internal CA

- The "Link" criticality assessment
  - Based on A. Nagurney's Unified Network Performance Measure
  - Applicable on road transport networks
- The "Node" criticality assessment
  - Based on a generalized transport operations value
  - Applicable on air and maritime transport networks
- The "Combined Link-and-Node" criticality assessment
  - Applicable on rail transport networks
  - Combination of the above for railway tracks and stations respectively

Description of the Framework

The "Adaptation measures" dimension

- Definition of adaptation measures: Investment combinations of different adaptation measures groups, associated to respective impacts of extreme weather events
- Having a total budget M, this can be allocated to different combinations of adaptation measures C_n
- The aim of each combination C_n is to minimize the impacts of specific extreme weather events
- Final objective: optimally allocate the available sources for investment M (budget), so as to minimize the economic losses due to the impact of extreme events

Description of the Framework

The Evaluation Framework

- Objective: determine the appropriate measures’ combinations C_n based on a finite budget M, so as to minimize the economic losses due to the impact of extreme events for each specific area extent

Description of the Framework

$$\overline{C_n}(\mathrm{M}) \rightarrow \arg\min \sum (\mathrm{P}_{\mathrm{E_i}} * s_{\mathrm{E_i}})$$

where:

- C_n = set of measures
- M = available budget (finite)
- $P_E * S_E$ = impact
- $S_E = S_{EI} + S_{ES}$
- $S_{ES} = t_d * d * v_t$
- E_i = events
- P_E = probability of an event E occurring
- S_E = severity of an event E
- S_{EI} = damage and rehabilitation costs
- S_{ES} = societal costs
- t_d = delay
- d = demand
- v_t = average value of time (of passenger and freight transport)

Conclusions

- Identification of the existing research and methodological gap in assessing climate change impacts on transport networks
- Description of an integrated sequential approach, aiming to address effectively all problem dimensions
- Identification of the Area extent as the common parameter
- Top-down approach from the central government perspective

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Thank you for your attention

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