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8 October 2014

Online at https://mpra.ub.uni-muenchen.de/61535/
MPRA Paper No. 61535, posted 25 January 2015 02:06 UTC

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Abstract

Climate change related disasters and extreme weather events are expected to significantly increase the risk of damages on networks, systems and assets. In view of these anticipated adverse effects, growing attention is placed on adaptation measures, in the form of preventive actions aiming to minimize induced hazards' negative impacts and to enhance the cross-sectorial resilience. The transportation sector is no stranger to this regime. Within this paper, a detailed desktop, literature and case-study review approach is adopted in order to identify transport-related adaptation measures and actions that are taken at a global and European level. Findings from national and international activities, along with relevant policies and strategies stemming from relevant organizations (IPCC, Bridging the Gap, etc.) are reviewed in terms of their hitherto and expected contribution in efficiently addressing climate change. In addition, proposed actions are clustered in terms of content (technical measures, ICT, legislative, etc.). In this way, the transferability and applicability of case-specific experiences throughout the world are highlighted through the consolidation of a common knowledge base regarding adaptation measures in the transportation sector. Findings are formulated in the form of an adaptation toolbox that can provide the basis for an improved decision making approach for different end-user for addressing climate change.

Introduction

Climate change related disasters and extreme weather events are expected to significantly increase the risk of damages on networks, systems and human assets. In view of these anticipated adverse effects, growing attention is placed on adaptation measures, in the form of preventive actions aiming to minimize induced hazards' negative impacts and to enhance cross-sectorial resilience. Transportation, as a key economic sector of today's society, is no stranger to this regime. The expected climate-related changes, as argued by (1,2) will impact both transportation infrastructures and networks of operations, independent of transportation means; an argument that, given the increased frequency and intensity of extreme weather events (EWE) and natural hazards (NH) observed worldwide in recent years, can no longer be dismissed as mere speculation. Rather, it should be addressed as a reality (1, 2, 3, 4). It is therefore pivotal to tackle such effects in a structured and coherent approach, highlighting those sets of measures and policies that can efficiently deal with climate change-induced impacts. Starting from a detailed desktop and literature review, in order to create a consolidated knowledge base on transportation-related adaptation measures and policies, this paper conducts the clustering of all reported measures in content structures (e.g. technical options, organizational and decision making structures, etc.) The work presented in this paper adopts the definition of adaptation to climate change as the "initiatives and measures that can reduce the vulnerability of natural and human systems against actual or expected climate change effects" (5). Though various scientific publications considering adaptation in transportation were published during the 1980s, they were limited to attempts to provide a definition that best suits the term. It was not until 1988, when the Intergovernmental Panel on Climate Change (IPCC) was established, that dedicated and focused efforts were made to provide potential solutions around the arising problem of climate change (6). However, despite the extensive research conducted in the field, the IPCC only mentioned adaptation in its 2nd Assessment Report in 1995 (7). The necessity of adaptation strategies against climate change implications was recognized in the panel's 3rd Assessment Report in 2001, stating that, because mitigation measures will not suffice to prevent climate change, adaptation measures and policies will be necessary (8).

The remainder of the paper is organized as follows: Section 2 presents the methodological approach followed within this paper, along with the materials that have been used. Section 3 reviews the pertinent literature on transportation-related adaptation measures to climate change and Section 4 clusters and discusses them, based on their content and the transport mode they mostly address. Finally, Section 5 concludes on the conducted research and proposes directions on future research in the field of climate change adaptation measures for the transportation sector.

Methodology

The approach presented herein aims to integrate existing knowledge on transportation-related adaptation measures to climate change under a content perspective, by utilizing research work already conducted in the field. The paper reviews articles from refereed journals, conference proceedings and technical reports since the late 1980s that provide insights and suggestions on measures for tackling the adverse effects of climate change on transportation networks and infrastructures. Additionally, it reviews reports issued among others by international organizations, committees and panels dealing with climate change, including the International Panel on Climate Change (worldwide), the European Environment Agency (EU), the European Topic Centre on Climate Change impacts, vulnerability and Adaptation (EU), the Transportation Research Board of the National Academies – Committee on Climate Change (US) and the World Bank (worldwide). Finally, it brings together findings from research projects conducted under the aid of European research funding mechanisms. Literature review findings are then consolidated in a tabular form based on the transportation mode they mostly address, before being clustered in one of the following structures:

- Organization and decision making processes
- Technical options and possibilities to reduce risk
- Procedural and operational options to mitigate risk
- Information flow and ICT support
- Decision and risk models
- Legislative

Discussion

Tables 1 to 4 summarize a series of suggested adaptation measures encountered during the literature review. They are classified per addressed mode and clustered based on their content. It is noteworthy that some measures can address more than one mode at the same time – for instance, the identification of risk-prone flooding locations and relocation of critical infrastructure included therein concerns road, rail and air transport at the same time. Based on the reviewed literature, impacts of climate change on transportation infrastructure and networks are more often than not results of flooding, as the latter can be caused either by sea level rise or by extreme weather conditions. The majority of the adaptation options listed in the Tables is under the road transport and inland waterway and maritime category. Adaptation measures in road transport are expected to monopolize interest in the near future, as they concern the dominant means of transport for everyday mobility in urban and regional areas. Regarding inland waterway and maritime transport, and given the fact that, due to sea level rise, water transport's role will be significantly upgraded, it comes by no surprise that related adaptation measures are so richly documented in the literature. Yet, it is surprising that rail and air transport lack alternatives, compared to the other modes, given that an increasing number of urban settlements tend to adopt the design of railway networks, and in addition, countries with large populations, such as the U.S, China or Russia, have a remarkably high share of air travel. The expected climatic changes could render both rail and air infrastructure vulnerable in the face of weather events, resulting in delays and loss of revenue.

Clustering the adaptation measures summarized in Tables 1 to 4 reveals the dominance of technical options versus all others (71 out of 146). This is, arguably, to be expected, as such solutions are often more straightforward in terms of implementation, compared to organizational or legislative measures, where potential bureaucracy may result in slow reaction times from the authorities.

TABLE 1 Road transport adaptation measures description and clustering

Organizational and decision making processes | Technical options | Procedural and operational options | Information flow and ICT support | Decision and risk models | Legislative options

R1: Construction of dikes and creation of flood barriers for protection against water *(17,10, 8)*	R16: Provision of reliable, instant and - if feasible- personalized information on duration of the incident and travel options *(13, 24)*	R31: Regular clearance of cycle lanes and sidewalks during winter *(13)*
R2: Innovative pavement materials resistant to corrosion *(13)*	R17: Roadside vegetation, absorbing generated heat, protecting roads *(13)*	R32: Development of intelligent feedback systems in vehicles to sustain? user attention *(9)*
R3: Improved drainage in intersections *(13)*	R18: Design of new heat-resistant asphalt mixes *(13, 17, 15, 10)*	R33: Conduction of public campaigns in order to raise public awareness regarding local hazard situation *(5, 8)*
R4: Elevation of coastal road networks *(18)*	R19: More heat-resilient bridge joints *(17, 15)*	R34: Priority plans that maintain access to hospitals, emergency stations *(13)*
R5: Design of and investment in new assets with "quick restoration" capability *(8)*	R20: Adaptation of timetables and service intensities under adverse weather conditions *(5, 25)*	R35: Definition of priority routes for road clearance in case of large scale impacts *(25, 26)*
R6: Setting and implementation of international standards for weather and emergency information *(5)*	R21: Need for alternate routes for freight transport in Arctic areas *(19)*	R36: Adoption of operational, physical, technical, procedural and institutional integration of weather and traffic control services *(8)*
R7: Consultation with and co-ordination of highway authorities, subcontractors, suppliers and key stakeholders to adjust adaptation strategies *(24)*	R22: Need for improvement of drainage-sewer systems as well as for more road-side rain pits *(13,10)*	R37: Review of maintenance contracts and procedures to make them flexible and effective even under rapidly changing weather conditions *(8, 13)*
R8: Provision of shelters for non-motorized transport *(26)*	R23: New asphalt mixes that help in faster drainage of standing water *(20)*	R38: Preparation and broad communication on disruptions and alternatives with the public, using a variety of communication channels *(5)*
R9: Preparation for sufficient salt stocks and road clearing equipment availability before and during winter or storm seasons *(8)*	R24: Enhancement of road layers to prevent washing-off *(13)*	R39: Tracking of "chain reactions" of extreme weather events, particularly in agglomeration areas *(5, 23)*
R10: Establishment of networks of urban, regional and national stakeholders: transport companies, authorities and users *(13)*	R25: Installation of signs that warn the driver/pedestrian on upcoming flooded network *(13)*	R40: Coordination of emergency plans amongst transport modes and networks *(25)*
R11: Issuance of educational and information material on emergency cases, planning and maintenance to related authorities *(5)*	R26: Strict speed limit enforcement during storms *(13)*	R41: Implementation of appropriate risk management procedures in order to be prepared for adverse conditions *(13)*
R12: Development of timely communication and coordination plans involving stakeholders and freight operator associations *(23)*	R27: Measures of protection against slope subsidence around road/rail network to avoid cut-off links *(21, 10)*	R42: Standardization of weather information and hazard warnings across Europe *(8)*
R13: Development of sustainable business models for the provision of emergency information systems *(8)*	R28: Additional pumping in tunnels *(10)*	R43: Assessment of logistics companies' risk exposure and establishment of appropriate adaptation plans *(5, 8)*
R14: Provision of cost-benefit assessment guidelines to logistic companies *(13, 8, 25)*	R29: Installation of wind-breakers *(13)*	
R15: Organization of the supply of trapped drivers/ passengers with the help of volunteers and aid organizations *(5)*	R30: New design standards relating components of road network (signs, lighting) enhancing protection of users *(26)*	

TABLE 2 Rail transport adaptation measures description and clustering

Organizational and decision making processes | Technical options | Procedural and operational options | Information flow and ICT support | Decision and risk models | Legislative options

Ra1: Construction of dikes to protect infrastructure from high water level *(17, 10)*	Ra13: Installation of redundancy and emergency capacity (pass-by trucks, switches, operation on opposite lane)	Ra25: Incorporation of climate change projections into the design of drainage to cope with predicted future flooding frequency and magnitude *(5)*
Ra2: Application of protective measures, e.g. barriers, trapbags *(13, 10)*	Ra14: Establishment of more drainage pits and bigger capacity on the run-off pipes *(13)*	Ra26: Installation of common control and steering centers including rail and emergency services *(13)*
Ra3: Reinforcement of existing barriers/dikes *(10)*	Ra15: Protection of underground stations and planning for emergency evacuation *(13)*	Ra27: Enhancement of flood resilience of rail infrastructure *(8)*
Ra4: Integration of different types of asset monitoring databases *(25)*	Ra16: Installation of local weather forecasting systems *(25)*	Ra28: Emergency planning and preparation with fire brigade and other emergency services; practice emergency plans for severe weather events *(25)*
Ra5: Improvement, maintenance and monitoring of infrastructure *(23)*	Ra17: Reduced speed limits during storms *(13)*	Ra29: Training for troubleshooting and information provision in case of events and in abnormal operations *(13)*
Ra6: Improved systems that warn drivers and repair teams about possible rail problems *(13)*	Ra18: Design of a risk-based approach for speed restrictions and line closures	Ra30: Planning for replacement services (e.g. bus) *(13)*
Ra7: Improved ventilation on underground stations *(13)*	Ra19: Preparation of logistic plans to deploy equipment and spare parts in case of hazards *(13)*	Ra31: Development of flood and wind/storm prediction models incorporating better weather forecasts and more detailed information on topography, infrastructure, geology and hydrology *(25)*
Ra8: Temperature monitoring-warning systems in underground infrastructure *(13)*	Ra20: Measures of protection against slope subsidence around road/rail network to avoid cut-off links *(21, 10)*	Ra32: Hazard, vulnerability & risk mapping in cooperation with weather services *(5, 8)*
Ra9: New design construction for minimization of rail stress *(15)*	Ra21: Elevation of rail infrastructure as well as bridges *(10)*	Ra33: Development of flood and wind/storm response strategies; establishment of meteorological thresholds and triggers for actions *(5)*
Ra10: Preference of continuous welded rails *(10)*	Ra22: Additional pumping in tunnels *(10)*	Ra34: Identification of critical locations; construction of further sub-surface drains in problematic flooding areas *(8)*
Ra11: Re-planning of rail schedules due to increased frequency of high temperatures *(10)*	Ra23: Protection of open-air rail infrastructure against winds (wind-breaker) *(13)*	Ra35: Planning of emergency routes or diversions, due to cut-off network *(13, 19)*
Ra12: Regular substitution of railroad base materials, due to thawing *(19)*	Ra24: Circuit breaker system for lines that move through urban environment *(13)*	

TABLE 3 Air transport adaptation measures description and clustering

Organizational and decision making processes | Technical options | Procedural and operational options | Information flow and ICT support | Decision and risk models | Legislative options

A1: Construction of barriers-dikes to protect infrastructure in coastal airports from water inundation *(10)*	A13: Realignment of runways, due to changeable cross-winds *(19, 11)*
A2: Elevation of runways *(10)*	A14: Implementation of SESAR developed technologies and procedures aiming to optimize capacity in disruptive conditions *(24)*
A3: Redesign of drainage system *(10)*	A15: Development of travel re-arrangements and additional costs for journeys in case of multi-modal traffic chains *(23)*
A4: Inclusion of climate change aspects in the ATM airport master plan	A16: Development of a measurement system to assess and compare the vulnerability of airports and airspace
A5: Capacity improvement of restricting equipment (e.g. snow removal equipment, air-conditioning)	A17: Transparency boost in the comparison of the impacts of disruptive events (consistent statistical evaluation processes) *(13)*
A6: Longer runways to accommodate aircrafts landing at high-density air *(17, 18, 10)*	A18: Improvement of local weather and disruptions forecast (forecasts with improved geographical and timely precision may help to reduce the disruptive impact) *(8)*
A7: Heat resilient runway tarmac *(10)*	A19: Identification of regions with possible permafrost thawing *(15)*
A8: Relocation of runways built on surfaces affected by thawing *(18)*	A20: Revised building-codes could limit implications of extreme weather events *(8)*
A9: Need for increased repairs on runways located upon ground affected by thawing *(10)*	A21: Planning of emergency routes or diversions, due to cut-off network *(13, 19)*
A10: Runways with tarmac mix that accelerates drainage of standing water *(20)*	A22: Exclusion of high-risk flood areas from any development activity *(13,10, 16)*
A11: Installation of wind-breakers *(13)*	A23: Development of evacuation plans and alternative routes *(15)*
A12: Reinforcement of airport infrastructure against flooding *(17)*	A24: Prohibition of construction near high-risk areas *(12, 10, 16)*

TABLE 4 Inland waterway and maritime transport adaptation measures description and clustering

Organizational and decision making processes	Technical options	Procedural and operational options	Information flow and ICT support	Decision and risk models	Legislative options

IWW-M1: Relocation of harbor infrastructure *(8, 10)*	IWW-M14: Production of more accurate weather forecasts through comparison of weather forecast model outputs against reliable observed data for the forecast location *(13)*	IWW-M27: Elevation of harbor infrastructure above possible surge level *(15,16)*	IWW-M40: Issuance of guidelines on the application of environmental legislation relevant to ports and waterways *(16)*
IWW-M2: Tsunami protection infrastructure *(8)*	IWW-M15: Insertion of heat-resilient materials to port construction procedure *(16)*	IWW-M28: Construction of barriers and protection walls to avoid water inundation *(15,10)*	IWW-M41: Technological innovation for fleet modernization, fleet operation, port & terminal infrastructure *(10, 18)*
IWW-M3: New design standards for ships for protection against larger waves or shallow channels/harbors *(16)*	IWW-M16: Constant monitoring of infrastructure environment temperatures *(16)*	IWW-M29: Stronger ship attachment mechanisms, cargo load/unload mechanisms *(22)*	IWW-M42: Collaboration between weather services, oceanographic institutes and other shareholders providing experience and resources *(8, 10)*
IWW-M4: Relocation, redesign and reinforcement of water-breaks for protection of harbor and general sea transport infrastructure against larger waves *(16)*	IWW-M17: Enhanced insulation and refrigeration of warehouses *(16)*	IWW-M30: Reinforcement of docks, cranes etc. to withstand violent winds and bigger waves *(10)*	IWW-M43: Enhancement of effectiveness and efficiency in new technologies, sensors for weather forecasting *(16)*
IWW-M5: Regular sediment removal from sea bed *(10, 18)*	IWW-M18: Regular maintenance and repair of damaged infrastructure *(16)*	IWW-M31: Regular monitoring of infrastructure conditions *(16)*	IWW-M44: Implementation of the Joint Statement of Environment & Inland Navigation Development by providing technical assistance *(13)*
IWW-M6: Infrastructure insurance to compensate for potential damage *(16)*	IWW-M19: Clarifications of models managing the safety investments in various port ownership situations *(15)*	IWW-M32: Design of water retention basins in case of severe flooding *(16)*	IWW-M45: Provision of adequate berths, anchorages and shore equipment to handle larger number of vessels *(15, 16)*
IWW-M7: Extension of functions and the integration of the River Information Services (RIS) systems *(15)*	IWW-M20: Increased access to harbors and new routes for ship transport *(10)*	IWW-M33: Development of a state-of-the-art waterway management system as well as further standardization and extension of waterway related information *(8, 15)*	IWW-M46: Improved infrastructure management by waterway administrations *(8)*
IWW-M8: Development of innovative methods for the improvement of river monitoring (shear stress, sediment transport, morpho-dynamics etc.) *(13)*	IWW-M21: Need for alternate routes for freight transport in Arctic areas *(19)*	IWW-M34: Establishment of a joint “task force” for the purposes of rapid reaction in cases of severe disturbances in navigation caused by hydrological/meteorological phenomena *(13)*	IWW-M47: Continuous and differentiated monitoring and analysis of the development of the river’s water discharge regime *(5)*
IWW-M9: Provision of vertical quays to accommodate transshipment under extreme low water conditions	IWW-M22: Creation of a European river engineering and IW transportation science partnership *(8, 13)*	IWW-M35: Operation of an integrated smart network of waterways across Europe *(15)*	IWW-M48: Structural modifications of river engineering works *(16)*
IWW-M10: Improvement of the quality and reliability of wind forecasts by using WRF (Limited Area Model) down to a 2 km resolution *(28)*	IWW-M23: Comparison and balance of ecological effects, transport objectives and planning accordingly *(5, 15)*	IWW-M36: Increase of awareness of different stakeholders on climate change impacts on IWT and related industries *(15)*	IWW-M49: Improved infrastructure management by waterway administrations *(13)*
IWW-M11: Responsibility allocation considering weather stations in ports *(8)*	IWW-M24: Creation of a European inland waterway space with minimal administrative barriers and with a maximally harmonized legislative and regulatory framework *(15, 16)*	IWW-M37: Increase of storage capacities for increased seasonal logistics buffers and additional value added services for logistics chain modifications *(16)*	IWW-M50: Creation of an efficient and harmonized regulatory framework *(15)*
IWW-M12: Improvement of transshipment infrastructure, making it effective under different water level conditions *(25)*	IWW-M25: Protection of infrastructure from water inundation *(10, 16)*	IWW-M38: Provision of adequate fendering systems (for vessels of higher damage sensitive lightweight structures) *(16)*	IWW-M51: Development of state-aid schemes to create innovative, adapted, efficient and more environmentally friendly vessels *(16)*
IWW-M13: Standardization and system requirements for adoption of technologies in ports by authorities and to create a way to enforce the implementation *(15)*	IWW-M26: Increased need for sediment removal from sea bed, result of larger waves and flood *(10, 14)*	IWW-M39: Collection, recording, visualization and sharing of information on water depths *(8, 16)*	

Concerning road transport adaptation measures (Table 1), due to the extent of road networks worldwide as well as the number of people using them for their mobility, any implications would result in millions of lost work hours, and various economic and social consequences. In response to that, measures must be taken to tackle this big, upcoming problem. It goes without question that maintenance procedure protocols need to be adapted to the ever changing conditions because the need for servicing networks and infrastructure under the impact of extreme weather events will be severe as the climate gradually changes (R37). In detail, road networks are at high risk in areas which are likely to be affected by water level rise. Especially, infrastructure which lies in close proximity to the shore should at least be elevated if not relocated or closed permanently (R4). Increased rainfall could lead to flooding problems in urban and rural networks. Thus, effective draining is crucial. While most of the road networks have similar draining requirements, intersections are a special category, which should be treated with special care. The fact that many intersections have mild or non-existent gradient makes the draining of water even harder. As a result, draining should be improved using bigger run-off pipes, special asphalt mixes (porous asphalt), and bigger storm drains (R3). Insufficient draining results in standing water, which reduces traction and leads to accidents. Speed limits should be strictly applied, so as for drivers to have more time to react to possible aquaplaning and to reduce the force of an impact to the driver (R26).

Except from flooding, intense rainfalls can cause slope subsidence. In many regions rainfall slopes, which have not be stabilized, can subside leading to rock falls and mudslides. Minor accidents, closed links or even human casualties have been reported in such occasions, thus protective measures should be planned and taken (R27).

Information flow measures are equally important as those of a more technical nature. Provision of information to users is very crucial. Public campaigns are a significant mean to raise awareness of users on the possible problems that may arise in the areas they reside in, making them more cautious and familiar with emergency solutions on problems, due to weather phenomenon (R33).

Regarding rail transport (Table 2), respective vehicles used for transport of passengers and goods should perform flawlessly under high temperatures (due to the changing climate). However, a safer option would be to re-plan the schedules and timetables in order to avoid time periods when temperatures peak throughout a day. That would reduce energy requirements from the vehicles themselves and will improve the journey for the users (Ra11). Though metro stations are underground, high temperatures can have an impact on them as many of them suffer from poor ventilation. Following the piston effect, the heat from the tunnels reaches the platforms, where the users are crowded, resulting in suffocating conditions. It has been reported that temperatures may even reach 47^{o} C on hot summer's days. As a result effective ventilation systems are a necessity (Ra7). Following the need for improved ventilation systems, a system for monitoring the environment temperatures must be applied. In cases where a system malfunction occurs, the system can detect increasing temperatures. If those temperatures exceed a set limit, then authorities must evacuate the station, preventing possible health problems for the users (Ra8). High temperatures result to rail buckling as well. Derailment, discomfort and longer travel times are results of the latter. Research has shown that continuous welded rails perform better under heat stress, avoiding the buckling phenomenon. Thus, installation of continuous instead of discontinuous rails is preferred in occasions when rail buckling due to increased temperatures is observed (Ra10).

Regarding air transport (Table 3), and as temperatures are expected to increase in many territories around the globe, airports will need to increase the length of their runways to allow airplanes to take-off without incidents. Due to the increased temperatures, the air becomes less thick and as a result there is not enough thrust for the airplanes to leave the ground, so a larger runway is required. Increased temperatures affect northern countries as well, in which many airports are constructed on ground that consists of ice or snow. These airports are in many cases just for military purposes or only for cargo airplanes. Nonetheless, these airports will have to be relocated, because thawing will undoubtedly have an effect on the runway materials, affecting safety on landing and takeoffs (A8). However, it must be pointed out that possible relocation of airport infrastructure due to thawing inflicted materials depends on the correct identification of the endangered areas and acts as prerequisite (A19).

As climate changes, precipitations will become more and more frequent and storms will intensify, leading to oftener flooded runways. Though, more advanced draining systems can be applied, another approach can be adopted. Porous asphalt can reduce flooding effects, as draining becomes easier. However, the mixture will have to be reinforced, because of the high loads with which airplanes strain the landing surface (A10). Additionally, hurricanes will also become stronger, resulting in more difficult takeoffs and landing procedures due to strong winds. As a result, windbreakers are inevitable if safety is to remain in a high level (A11). In cases where windbreakers are not an option, relocation of the runways must be undertaken. After a complete research on the direction and intensity of the occurring winds, runways must be placed in such a way as to avoid side-winds that may affect the direction of approaching aircrafts (A13).

Regarding maritime and inland waterway transport, the main sources of problems are wave formations. Especially in certain areas (e.g. Japan) a special wave formation type has been observed by scientists. Those high energy waves (tsunamis) are one of the biggest dangers for harbor infrastructure. In areas, where tsunamis are frequent, special infrastructure needs to be applied to protect ships and critical infrastructure (IWW-M2). Given that winds will grow stronger and sea level will rise, waves will inevitably become bigger. As a result, fortification of the water-breaks needs to take place as well as relocation of many of them in deeper waters, so as to be more effective.

Finally, water-breaks (artificial rock formations placed on a certain distance from harbors) can account for energy a reduction of incoming waves and therefore protect infrastructure (IWW-M4). Other than protection of critical infrastructure, vessels must also be modified in order to withstand high energy wave impacts. Especially ships that carry sensitive and environmentally unfriendly cargo (e.g. tankers) must have improved fendering systems applied to them (IWW-M38).

Conclusions

A methodological approach towards the clustering of adaptation measures for the protection and resilience enhancement of transport infrastructure and networks has been presented and applied in the framework of this paper. The approach integrated existing isolated knowledge on adaptation measures reported in the literature in a consolidated database, in tabular form and the findings have been discussed. Reported adaptation measures have been clustered in various content structures and as shown, measures can be dynamically contained in more than one set, thus simplifying the decision process on the part of authorities as to which set optimally suits each situation (characterized by the prevailing climatic, geographic and other conditions).

The approach has the potential of being extended in the form of a roadmap of actions and implemented under a Decision Support System. Besides highlighting optimal strategies, the Decision Support System can indicate potential strengths and weaknesses of thus far applied climate change adaptation measures, as well as assisting decision makers. Coupled with existing climatic scenarios, customized for respective regions and areas, the adaptation measures, policies and strategies reported herein can be used right away by authorities in order to tackle climate change-induced impacts in the transportation sector.

References

(1) Mitsakis, E., Stamos, I., Kral, S., Claus D., Nokala, M., Salanova, J.M., Ayfadopoulou, G. 2014. “A data-driven method for assessing the resilience of the European passenger transport network during extreme weather events”. Transportation Research Board 93rd Annual Meeting, Washington D.C., January 2014.

(2) Mitsakis, E., Stamos, I., Papanikolaou, A., Ayfadopoulou, G., Kontoes, H. Assessment of climate change impacts and extreme weather events on transport networks: Case study of the 2007 wildfires in Peloponnesus. *Natural Hazards*, Vol. 72, no. 1, 2013, pp. 87-107.

(3) Mitsakis E., Stamos I., Diakakis M., Salanova Grau J.M. Impacts of high intensity storms on urban transportation: Applying traffic flow control methodologies for quantifying the effects. *International Journal of Environmental Science and Technology*, 2014.
DOI: 10.1007/s13762-014-0573-4

(4) Aparicio, A., Leitner, M., Mylne, K., Palin, E., and Sobrino, N. Support to transport and environment assessments – adaptation to climate change in the transport sector. European Environment Agency (EEA), 2013.

(5) Parry, M., Canziani, O., Palutikof, J., van der Linden, P., and Hanson, C.E. (Eds.). *Climate change 2007: impacts, adaptation and vulnerability, contribution of Working Group II to the 4th Assessment Report of the IPPC*. Cambridge University Press, Cambridge, UK and New York, NY, USA, 2007.

(6) Houghton, J., Jenkins, G., Ephraums, J. (Eds.). *Climate change: Scientific assessment of climate change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, 1990.

(7) Houghton, J., Meira Gilho, L., Callander, B., Harris, N., Kattenberg, A. and Maskell, K. (Eds.). *Climate change 1995: The science of climate change: contribution of working group I to the second assessment report of the Intergovernmental Panel on Climate Change (Vol. 2)*. Cambridge University Press, Cambridge, UK and New York, NY, USA, 1996.

(8) McCarthy, J., Canziani, O., Leary, N., Dokken, D., White, K. (Eds.). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, 2001.

(9) Rosenzweig, C. and Parry, M. Potential impact of climate change on world food supply. *Nature* 367, pp. 133-138

(10) Transportation Research Board Special Report 290, Potential Impacts of Climate Change on U.S. Transportation, 2008.

(11) Koetse, M. J., and Rietveld, P. The impact of climate change and weather on transport: An overview of empirical findings, *Transportation Research* Part D Vol. 14, 2009, pp. 205–221.

(12) Stern, N. The economics of climate change. *The American Economic Review*, 2008, pp. 1-37.

(13) German Development Cooperation. Adapting urban transport to climate change; contribution of the Wupertal institute in GTZ’s Sustainable Transport Sourcebook, module 5f, 2009.

(14) Taylor, M. A., & Philp, M. Adapting to climate change-implications for transport infrastructure, transport systems and travel behaviour. *Road & Transport Research: A Journal of Australian and New Zealand Research and Practice*, Vol. 19, no. 4, 2010, p. 66.

(15) Transportation Research Board of the National Academies. Adapting Transportation to the Impacts of Climate Change, State of Practice 2011, Number E-C152, Washington, D.C., June, 2011.

(16) United Nations Conference on Trade and Development. Climate Change Impacts and Adaptations: A Challenge for Global Ports, Geneva, Switzerland, September 2011.

(17) Schwartz, H. G. Jr. (2010) America's Climate Choices: Adaptation – A Challenge to the Transportation Industry, *Transportation Research Board Webinar,* Nov. 3, 2010, 69 pp.

(18) Karl, Thomas R., Jerry M. Melillo, and Thomas C. Peterson, eds. Global climate change impacts in the United States. Cambridge University Press, 2009.

(19) Walker, L., Figliozzi, A. M., Haire, A. R., MacArthur, J. Climate Action Plans and Long-Range Transportation Plans in the Pacific Northwest: a review of the state of practice, Transportation Research Forum, Washington DC, USA, March 2010.

(20) Matthews, T. Climate Change Adaptation in Urban Systems: Strategies for Planning Regimes, Urban Research Program, Research Paper 32, Brisbane, Australia January 2011.

(21) Stocker, Thomas F., (Eds.) Climate change 2013: The physical science basis. *Working Group I Contribution to the Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5),* Cambridge Univ Press, New York, 2013.

(22) Eisenack, K., Stecker, R., Reckien, D., and Hoffman, E. Adaptation to Climate Change in the Transport Sector: A review. Potsdam Institute for Climate Impact Research (PIK), Potsdam, May 2011.

(23) Bipartisan Policy Center, National Transportation Policy Project (2009) Transportation Adaptation to Global Climate Change, supported by the Rockefeller Foundation

(24) De Bruin, K., Dellink, R. B. , Ruijs, A., Bolwidt, L., Van Buuren, A., Graveland, J., De Groot, R. S., Kuikman, P. J., Reinhard, S., Roetter, R. P., Tassone, V. C., Verhagen, A., and Van Ierland, E. C. (2009). Adapting to climate change in The Netherlands: an inventory of climate adaptation options and ranking of alternatives, *Climate change,* 95, 1-2, pp. 23-45 April

(25) Kaufman, S., Qing, C., Levenson, N., and Hanson, M. Transportation During and After Hurricane Sandy. Rudin Center for Transportation, NYU Wagner Graduate School of Public Service, November 2012.

(26) Stenek, V., Amado, C., Connell, R., Palin, O., Wright, S., Pope, B., Hunter, J., McGregor, J., Morgan, W., Stanley, B., Washington, R., Liverman, D., Sherwin, H., Kapelus, P., Andrande, C. and Pabon, D. Climate Risk and Business Ports, International Finance Corporation (World Bank Group), March 2011, Cartagena, Colombia