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Initiatives in climate change impact assessment and adaptation for inland transport

Draft chapter IV - Effective adaptation of transport systems and assets to the changing climate

Submitted by PIANC

I. Types of adaptation measures

1. The IPCC[1] define adaptation as 'The process of adjustment to actual or expected climate and its effects', adding that 'In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects'.

2. The process of adjustment to reduce vulnerability to climate change impacts can take many forms. In some cases, the adaptation objective may be to avoid an adverse effect of climate change. In others the intention may be to reduce or minimise adverse effects to a level deemed acceptable. If it is not possible to avoid harm, adaptation may also involve strengthening resilience so as to cope with and then recover quickly after a hazardous disturbance or event.

3. The widely recognised IPCC AR5 categorisation system[2] identifies adaptation measures under three main categories: physical/structural, social, and institutional. The term

[1] IPCC, 2014: Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130

[2] Noble, I.R., S. Huq, Y.A. Anokhin, J. Carmin, D. Goudou, F.P. Lansigan, B. Osman-Elasha, and A. Villamizar, 2014: Adaptation needs and options. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 833-868.

measures in this context refers to a variety of actions, responses and interventions. Table XX provides examples of adaptation measures relevant to transport assets and systems.

Table XX
Examples of adaptation measures relevant to transport assets, networks and systems

Category	Generic examples	Mode-specific examples (TO BE ADDED)
Structural/ physical measures		
Engineered/ built environment	*Retrofit, replace or (re-)design assets to reinforce, strengthen, raise, etc.; invest in flexible/responsive/demountable assets; relocate vulnerable assets or operations; improve flood/erosion protection standards or drainage capacity; provide or increase shelters or storage facilities and capacity; maintain assets and equipment; select climate-proof materials or equipment; ensure water supply/waste reception and treatment; provide alternatives, redundancy or back-up critical infrastructure (e.g. energy, access)*	
Technological	*Early warning systems; hazard mapping; real time monitoring and forecasting systems; SMART management systems; water management technologies; insulation or cooling technologies*	
Ecosystem-based	*Green and blue infrastructure; nature-based solutions including to strengthen important ecosystem services (e.g. flood protection; erosion control; carbon storage); water management; land-use*	
Social measures		
Educational	*Awareness raising; engagement; training; toolbox talks; ownership of solutions*	
Operational	*Risk assessment; risk mapping; working practices; operational protocols; asset inspection; safe routes/diversions; identify alternatives; flexible scheduling/staffing; guidelines*	
Information-related	*Real time monitoring; record keeping; data management; information sharing protocols; technology transfer*	
Behavioural	*Emergency response procedures and drills; prioritise inspection and maintenance activities; adaptive management protocols; diversification*	
Institutional measures		
Economic	*Contingency or disaster response funds; demonstrated resilience incentives; investment pre-conditions for new infrastructure; financial penalties; insurance requirements; grants and loans*	
Regulation	*Health and safety requirements; standards and codes of practice; non-compliance enforcement and penalties; legal protection for vulnerable habitats with risk reduction role*	
Policy and programmes	*Strategic adaptation planning (local/regional/international); zoning according to risk; set back, buffer area or*	

	relocation policies; build-back-better (or out-of-harm's-way) policies; diversification	

II. Guiding principles for selecting appropriate measures

4. Prior to selecting and confirming adaptation measures relevant to the system or asset(s) exposed to climate change risks, it is good practice to consider the following principles:

- avoid maladaptation; seek adaptive solutions
- anticipate interdependencies; foster collaboration
- accommodate uncertainties
- put a cost on inaction.

5. Each of these is elaborated below to explain its relevance to the process of selecting the most appropriate adaptation option(s).

- Avoiding maladaptation, seeking adaptive solutions

6. **Maladaptation** occurs when an adaptation action (or inaction) results in greater vulnerability, increased greenhouse gas emissions, or other adverse effects on well-being. Such impacts may be experienced in another location or affect another sector.

7. Maladaptation is usually an unintended consequence of a decision that has not taken account of the wider system context, including spatial or temporal scale, and the possibility of cascading failures in inter-related systems.

8. Maladaptation of a transport asset could result from an inflexible response to an anticipated change in a climate-related parameter culminating in under- or over-design, and resulting in a stranded asset or wasted investment respectively[3]. Some examples of potential maladaptation related to the infrastructure design process for new, replacement or retrofitted infrastructure are presented in Table YY.

9. Where there is a risk of maladaptation, adopting alternative adaptive solutions (i.e., solutions that accommodate uncertainty or can be modified if the actual change in a climate-related variable varies from that originally foreseen) can often reduce the likelihood of increasing vulnerability or deteriorating physical or material well-being over time.

10. Adaptive management is similarly an important concept, including for existing infrastructure. A combination of good data and inbuilt flexibility can help avoid maladaptation and deliver resilient solutions using local monitoring to help inform 'just in time' investment decisions as conditions require.

Table YY

Examples of design decisions that may result in maladaptation, and alternative 'adaptive' solutions

Design challenge	Solution that potentially represents maladaptation	Alternative 'adaptive' solution
Uncertainty about the design height of a new flood defence	The design height of an inflexible flood protection structure with a design life of 50+ years is informed by river flow forecasts derived from a single, mid-range, climate change scenario.	The flood protection design explicitly incorporates options to raise and strengthen the structure as conditions change. There may be an element of additional cost[4] (for example, buying a strip of additional land alongside the structure to enable its future raising) but such

3 PIANC WG 178, 2020; PIANC TN1, 2022

4 The World Bank reports that the extra cost of building resilience into infrastructure systems (including transport) in low- and middle-income countries typically represents around 3% of overall investment requirements (Hallegatte et al., 2019). In return, reduced disruption and reduced economic impacts yield a benefit of $4 for each dollar invested in resilience.

	Risk: an unacceptable frequency of overtopping within ~20 years if temperature increases significantly exceed the mid-range scenario, resulting in higher seasonal flow rates and/or in the frequency and severity of extreme rainfall causing peaks in river flow.	an investment should help to avoid a situation where the structure may have to be replaced entirely in 20 years.
Uncertainty about the volumetric capacity needed for a new drainage scheme	The wide range of projections for changes in seasonal rainfall and in the magnitude of extreme precipitation events make it difficult to determine the required drainage capacity for a new development site. The design therefore assumes a ‘mid-point’ across the projections. Risk: the drainage capacity is overwhelmed, causing inundation of the site, compromising the continued efficient operation of the entire facility.	The uncertainty is recognised and accommodated through some combination of: - engineering redundancy into the project by significantly increasing drainage capacity at marginal additional cost - accepting the inundation risk but incorporating preferential flow routes and sacrificial areas for water storage into the site design; purchase of pumps to facilitate rapid evacuation of water post-event - relocating or ‘flood-proofing’ critical assets or equipment located in risk zone
Uncertainty about the design height of a new breakwater	The design height of a new rock breakwater with an intended life of 40+ years is based on a high-end (or pessimistic) sea level rise plus an increased storminess scenario, which together significantly increase the construction cost. Risk: if sea levels rise more slowly than the selected scenario, or if storm severity does not increase as anticipated, the extra cost incurred means an opportunity to carry out an additional adaptation project elsewhere may have been missed through lack of funding.	The foundations of the breakwater are designed and constructed so as to physically support a breakwater of the original design height, but the initial breakwater height is selected to protect against conditions projected to occur in the next 20 years. While a review will be needed, and additional height may need to be added in due course, the short-medium term savings associated with the significantly reduced rock quantity enable another urgent adaptation project to be progressed in the meantime.
Lack of climate change data [DOES THE SAME OR A SIMILAR EXAMPLE WORK ROAD A ROAD BRIDGE?]	A jetty is badly damaged by strong winds and wave action during a tropical cyclone, leaving an island in a small island developing state unable to import goods by sea for many months. A lack of climate change data means the replacement is simply designed on a like-for-like basis. Risk: climate change increases the severity or frequency of tropical cyclones, meaning that the replacement structure will be badly damaged.	The replacement jetty is designed to fail in a controlled manner, incorporating a hierarchy of structural capacities (e.g. ensuring the deck fails before the its connections to the wharf[5]). This minimises the risk of catastrophic damage to the substructure. Demountable elements (e.g. decking) many also be included in the design. If a warning system is put in place, these elements can be removed and stored safely, enabling rapid post-event reinstatement of marine access.
	PLEASE ADD OTHER EXAMPLES MORE APPROPRIATE TO ROAD, RAIL, ETC.	

11. A different example of potential maladaptation arises in certain situations if the option of transformational change is not considered. Assume an organisation makes a significant investment to raise the quay walls in a port to prevent more frequent overtopping associated with sea level rise, without considering the wider system including the location and elevation of the port access road. If it subsequently proves technically or financially infeasible to raise the road to adapt to the combined effects of rising sea levels and increasing groundwater levels, the investment to raise the quay walls may have been futile. This scenario is illustrative of a situation in which transformational rather than incremental change – relocating the affected port facilities rather than modifying existing infrastructure – may have represented a better long-term solution.

5 PIANC 2020

12. The term **transformational change** is often used in situations where climate-induced hazards (such as more frequent flooding or droughts, or increased rates of erosion) will make sustaining an asset or operation in-situ infeasible. Options such as replacement or relocation therefore need to be considered. Transformational change may also be an appropriate response where an adaptation action would significantly increase greenhouse gas (GHG) emissions. For example, as agricultural production shifts in response to changing weather patterns, new transport infrastructure may be required. The relatively lower GHG emissions per tonne transported for bulk goods may mean that shifting to inland waterway transport or short sea shipping where these options are available, helps avoid the net increase in emissions associated with the alternative of road transport (developing new road networks to accommodate additional trucks, or continuing to rely on transport by trucks over much longer distances).

13. To reduce the risk of maladaptation, adaptation decisions should always take into account the wider system context, the residual level of uncertainty, and the associated potential for significant unintended consequences.

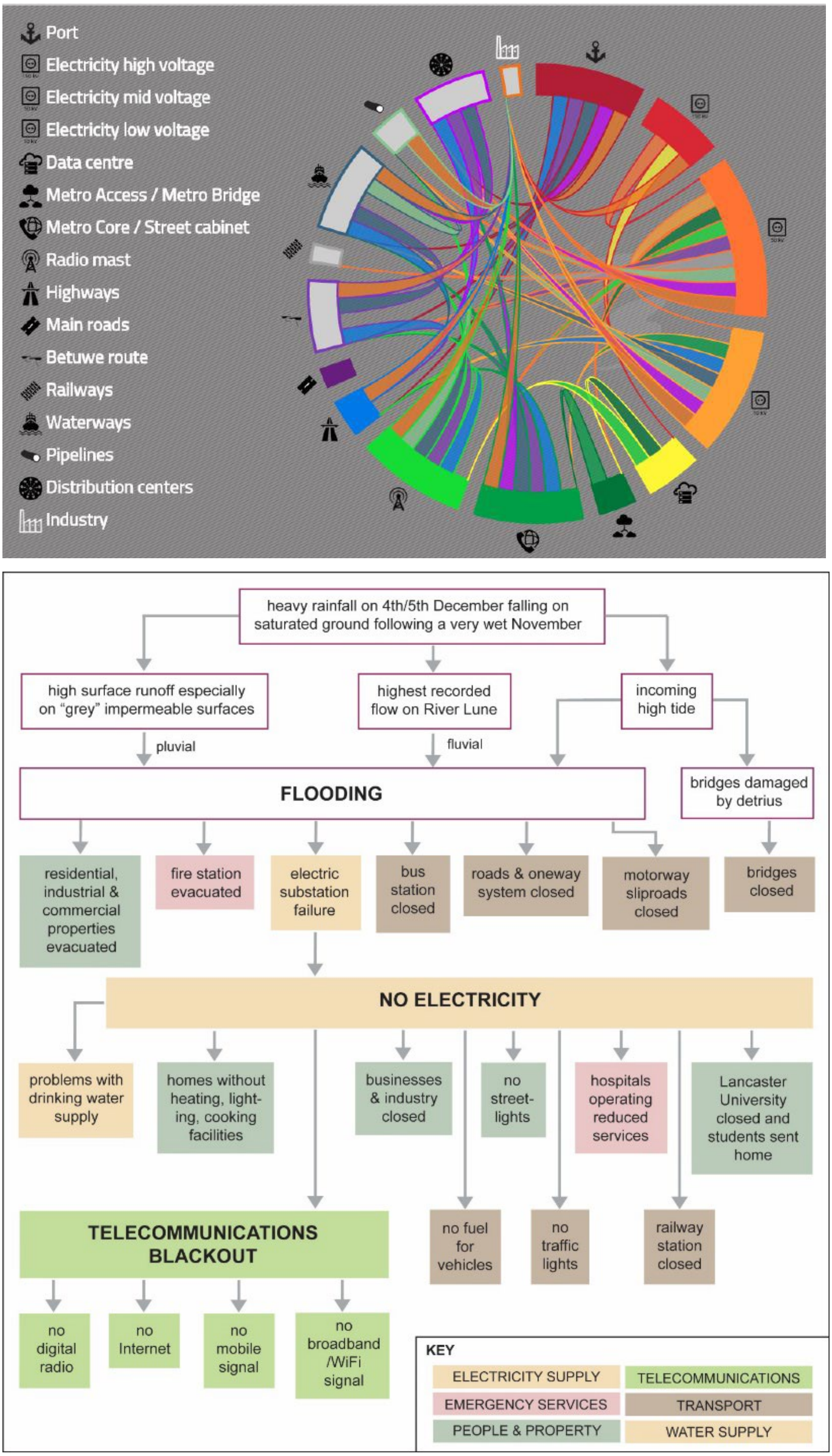
- Anticipating interdependencies, fostering collaboration

14. Transportation is a system. Transport infrastructure and other assets connect a network that facilitates mobility and underpins supply chains. Transportation systems operate within a wider system of systems. In a climate change context, the efficient operation of transport systems depends on the resilience, not only of other transport modes, but of other service and utility providers (energy supply, telecommunications/data services, flood protection, water supply, etc.). Figure XX illustrates these **interdependencies** in relation to an assessment of the impacts of extreme weather on the Port of Rotterdam in The Netherlands.

15. Climate change impacts, including failures associated with more frequent or severe extreme events, can cascade through interlinked and interdependent systems. Figure YY demonstrates how a failure in one or more services, directly and indirectly impacts other services, operations, and organisations within the system. This Figure depicts a multi-hazard rainfall event associated with Storm Desmond in North-West England in 2015[6].

6 Ferranti, E., Chapman, L. and Whyatt, D., 2017. A Perfect Storm? The collapse of Lancaster's critical infrastructure networks following intense rainfall on 4/5 December 2015. Weather, 72(1), pp.3-7.

Figure YY
Port of Rotterdam interlinkages between port operations and services/utilities[7]



16. As well as operational impacts, cascading failures can have significant economic consequences. WSP[8] (2020) conclude that the costs of indirect or cascading impacts can be between 1.3 and 3 times those of the direct impacts of infrastructure failures, depending on the approaches and models used, and the range of assumptions in those models.

17. Natural systems can also be directly and indirectly impacted by the changing climate, including as a result of cascading failures. In some locations, the resilience of transport systems depends on the resilience of the natural environment. Healthy marshes, mangroves and other vegetated habitats provide a buffer against sea level rise, storm damage or wave energy, helping to protect transport infrastructure from flooding or erosion. Other habitats act as natural flood storage or water retention facilities; some sequester and store carbon. Where these habitats are adversely impacted by climate change or by human activities, their ability to deliver these important ecosystem services is compromised. Understanding such interdependencies, and working with nature to protect and strengthen the resilience of natural systems by adopting nature-based solutions can help to avoid or reduce the requirement to invest in expensive 'grey' adaptation measures.

18. Decisions on adaptation measures will typically be taken by the operator of the asset or network. To be most effective, however, the process of identifying adaptation measures will often benefit from **collaboration** with relevant stakeholders. If the process of selecting appropriate adaptation measures takes place at the most appropriate scale and recognises relevant interdependencies, maladaptation can be avoided, the risk of cascading failures minimised, and opportunities for shared solutions and costs identified.

- Accommodating uncertainty [MAYBE THIS SHOULD BE MOVED TO BECOME THE FIRST HEADING IN SECTION II?]

19. **Uncertainty** about exactly how quickly the climate will change *[comment: to verify if reference be made to earlier section of source of uncertainty or it is mentioned here]*, and therefore when and how often critical thresholds will be crossed, can lead to decision paralysis in terms of which adaptation measures to implement and when. PIANC (2022)[9] aims to help decision makers by providing guidance on:

- Recognising and understanding sources of uncertainty, and how uncertainty translates into risks that impact on decision making processes
- Developing practical strategies for reducing, dealing with or otherwise accommodating uncertainty so as to avoid decision paralysis while also reducing potential maladaptation.

20. The main recommendations of the PIANC guidance, which are relevant to all types of transport infrastructure when adaptation options are being considered, are:

21. For permanent assets or long-term activities with a design life or planning horizon of more than 10 years, reduce reliance on the use of past data to predict low probability future events; rather refer to an appropriate range of climate change scenarios[10]

[to be checked if these bullet points should be here or rater make elsewhere]

- For major, long-term investments or when adapting particularly sensitive assets, consider a full range of climate change scenarios; carry out sensitivity testing on unlikely-but-plausible scenarios

7 https://www.deltares.nl/app/uploads/2015/04/PB_Impact-of-Extreme-Weather-on-the-Port-of-Rotterdam.pdf. Created using Circle - Critical Infrastructures: Relations and Consequences for Life and Environment) - a tool to support the analysis of domino effects of critical infrastructures. See https://circle.deltares.org/

8 WSP (2020). Interacting risks in infrastructure and the built and natural environments. Research in support of the UK's Third Climate Change Risk Assessment Evidence Report.

9 PIANC TN1

10 PIANC 2022

- Prepare for the unprecedented; consider the risk of joint occurrences, or cascading failures where interdependencies exist between natural and socio-economic systems and sub-systems
- Seek adaptive and versatile solutions that can be modified as conditions change; build in engineered or operational redundancy for critical assets, operations or systems; implement an adaptive management philosophy including monitoring to inform decision making (see examples in Table YY)
- Where appropriate, design structures to fail 'gracefully', in a controlled manner, rather than catastrophically; take steps to manage the consequences of failure, for example by including sacrificial components, or climate-proofing critical assets in the at-risk area (e.g. bunding or raising; nominating preferred inundation areas; raising electricity supply points; improving drainage capacity) (see examples in Table YY)
- Consider non-structural solutions (e.g. operational, behavioural, institutional; see Table XX) as well as structural interventions: such options may be more flexible, less expensive, and easier to justify and implement in the short to medium term; they may also help to protect operational continuity while solutions requiring major investment are explored
- Explore no-regret options that provide benefits under any foreseeable climate scenario including present day climate (i.e. the benefits will be realised irrespective of how climate variables change over time)
- Consider win-win solutions that provide benefits multiple sectors or organisations. Engaging with stakeholders before adaptation decisions are made can enable the identification of measures that address a range of impacts. Shared solutions that deliver a range of co-benefits, may provide an opportunity to share implementation costs, in turn reducing the burden on the individual operator.

22. As elaborated below, developing adaptation pathways can help dealing with uncertainty as the steps on the pathway are determined by monitoring and other evidence.

- Recognising that inaction has a cost

23. Climate change is a risk to the operational continuity of transport systems. It threatens not only individual assets but also supply chains, and therefore economies and livelihoods.

24. **Inaction** – or failing to act to adapt – has associated cost consequences. These costs, which may be financial/economic, legal/contractual, reputational or a combination of these, can be significant if inaction leaves the organisation or system exposed to damage or disruption.

25. Inaction in this context does not only mean a failure to raise, strengthen, or otherwise modify transport systems or assets. Costs can be incurred if infrastructure is not properly maintained. Inaction also covers failing to monitor (e.g. to understand trends, support early warning, and inform decisions); and failing to assess risks, prepare and plan accordingly.

Climate adaptation is a strategic move not a charitable act. It ensures resilience, risk management, and supply chain support in the face of the climate crisis. Governments, corporations, and impact investors [that] fail to incorporate climate adaptation measures into their strategies are not only missing out on returns, but also endangering their value chains.[11]

26. By reducing risk, adaptation action delivers multiple benefits. These benefits can be described as the triple dividend[12] because taking action to strengthen resilience and adapt:

- Helps avoid or reduce economic losses

11 https://www.goldstandard.org/news/the-business-case-for-climate-adaptation-why-its-a-profitable-investment

12 WRI and GCA, 2019. ADAPT NOW: A global call for leadership on climate resilience. World Resources Institute and the Global Center on Adaptation. September 2019. https://www.wri.org/initiatives/global-commission-adaptation/adapt-now-report

- Brings positive gains through risk-reduction, safeguarding investment and enabling increased productivity
- Delivers additional social and environmental benefits.

27. Understanding and quantifying the potential costs associated with inaction can prove crucial in justifying investment in adaptation measures. Avoided damage- and disruption-related losses represent a key benefit of investing in strengthened resilience, and there is growing evidence[13] [14] that early investment in climate change adaptation and strengthened resilience delivers good value for money. The process of selecting appropriate adaptation measures therefore needs to recognise this benefit by identifying and quantifying the damage and disruption that will be reduced or avoided as a result of implementing such measures.

28. Not all measures to reduce damage and disruption to transport systems are structural. Where resources are limited or where there is significant residual uncertainty, targeted monitoring programmes and various non-structural measures can have a vital risk reduction role. Vulnerability mapping, capacity building, early warning systems[15], disaster response plans, contingency plans including identifying operational alternatives (for example for access, or for storage), together with certain institutional interventions are relatively low-cost risk reduction options likely to represent good value for money for many transport operators.

29. Other no regret or 'quick win' measures that can significantly improve preparedness and contribute to the strengthened resilience of existing operations include prioritising:

- asset and network maintenance activities (e.g. of drainage systems, flood defences and vegetation management)
- the relocation of sensitive equipment
- flood-proofing or heat-proofing existing critical infrastructure
- the introduction of digital tools and solutions.

30. Furthermore, retrofitting can be complex and expensive, so significant benefits can be realised if operational or management changes enable the continued use of an asset until such time as it would in any case require replacement.

III. Evaluating options and developing an adaptation strategy

- Adaptation pathways

31. When considering possible measures to strengthen resilience and adapt transport assets and networks, a single solution is often not achievable. Climate change adaptation measures are typically explored simultaneously or implemented in-combination.

32. As indicated above, **adaptation pathways** provide an increasingly important model for planning adaptation interventions in the face of uncertainty. They are also useful where there is a lack of data, and they can help adaptation planning in situations where a future transformational change may be needed.

33. Adaptation pathways illustrate alternative routes towards a defined objective. They describe sequences of actions (measures, modifications, investments, etc.) that can be implemented progressively, depending on how the future unfolds and on the development of knowledge[16]. They may be centred around performance-thresholds or transformation

13 Hallegatte, Stephane; Rentschler, Jun; Rozenberg, Julie. 2019. Lifelines: The Resilient Infrastructure Opportunity. Sustainable Infrastructure. © Washington, DC: World Bank. http://hdl.handle.net/10986/31805 License: CC BY 3.0 IGO.

14 Watkiss, P., Cimato, F., Hunt, A. (2021). Monetary Valuation of Risks and Opportunities in CCRA3. Supplementary Report for UK Climate Change Risk Assessment 3, prepared for the Climate Change Committee, London, UK. https://www.ukclimaterisk.org/wp-content/uploads/2021/06/Monetary-Valuation-of-Risks-and-Opportunities-in-CCRA3.pdf CCRA3 co-funded by EU Horizon 2020 RTD COACCH project.

15 24 hours' warning of a storm or heatwave can reduce losses by 30% (WRI and GCA, 2019)

16 Brooke et al., 2024

objectives. Adaptation pathways are particularly well-suited to climate change adaptation needs as their realisation is based on monitoring outcomes and reflexive learning[17]. The first steps such a pathway may comprise temporary or low-regret measures, helping to ensure operational continuity while data are gathered or uncertainties are addressed, and longer term, sometimes more complex and/or costly responses are developed.

[ADD REFERENCE TO / CONTENT FROM ADAPTATION PATHWAYS DOCUMENT]

- The role of monitoring

34. Monitoring plays a key role in climate change preparedness and adaptation decision-making, helping to inform many different decisions including when action is needed. Initiating a monitoring programme if one does not already exist can be an important early adaptation measure, representing very good value for money. Monitoring does not always need to be sophisticated: it should be proportionate and fit-for-purpose.

35. Collecting, storing, managing and interrogating local **hydro-meteorological data** (also **oceanographic** data for marine and coastal transport infrastructure) enables operators to compare observed trends with (say) national or downscaled projections. Local information can help inform decisions on when a critical threshold(s) is likely to be exceeded, or when levels of risk are likely to become unacceptable. These types of data inform location-specific adaptive management actions, support just-in-time decision making, and facilitate the selection of optimal design criteria. Real-time monitoring can also underpin early warning systems.

36. Monitoring the **condition and performance** of physical assets and systems (structural integrity, system health…) are key to understanding when an intervention is required or when a measure should be implemented. This is particularly important if climate change impacts are exacerbating deterioration or adversely impacting on the design life of an asset or piece of equipment (e.g. due to more frequent overtopping, or increased rates of corrosion due to increasing acidity). As retrofitting can be costly and complex, it is important to understand and be able to optimise residual asset life, to recognise the need for operational or design redundancy, and to have time to explore availability of alternatives.

37. Recording **post-event data** from extreme weather events helps validate predictions about likely impact zones or inform models describing future conditions. Knowledge about the actual costs/losses and consequences arising from extreme or atypical events causing damage, disruption or downtime can be used to support the business case for investment in future preventative action. Knowledge about performance of already-implemented adaptation and resilience measures similarly helps inform decisions on future interventions, modifications, etc.

- The option evaluation process

38. Although the detail will vary between organisations, the process for selecting and evaluating climate change adaptation options is likely to include assembling and screening a long-list of options and then carrying out a more-detailed evaluation of a short-list of potentially viable measures.

39. A long-list based on (combinations of) the types of measures described in Table XX should include measures that are compatible with the organisation's adaptation objectives, technically feasible, and capable of delivering the level of risk reduction needed. These can then be screened using criteria derived from Section II, for example:

- Is the risk of maladaptation avoided/minimised?
- Can the measure(s) be modified or adapted as conditions change?
- Does transformational change need to be considered?
- Are interdependencies recognised and accommodated?
- Are there opportunities for co-benefits/is collaboration appropriate?

[17] PIANC 2022

- Is uncertainty adequately accommodated?

40. Other screening criteria[18] could include relative cost; maintenance or management requirements; potential for adverse impacts on physical or natural environment or heritage assets; and ease of implementation (for example, is the option a no or low-regret measure that will deliver benefits irrespective of how the climate changes?)

41. The evaluation methods then applied to a short-list of measures need to be appropriate to the climate change context[19]. Economic assessments that only extrapolate from past experience may no longer be fit-for-purpose if future climate risks are to be incorporated. Conventional cost-benefit assessment or net present value calculations may not adequately reflect climate change complexities even with low discount rates. These methods do not deal well with uncertainty so are most useful where the climate change adaptation planning horizon is short (e.g. ten years or less) and where climate risk probabilities are known and/or sensitivity is small[20].

42. As highlighted elsewhere in this chapter, difficult-to-quantify social and environmental impacts can be important in understanding the full consequences (positive or negative) of a particular measure or combination of measures. Potential upstream, downstream or transboundary costs and benefits should therefore be scrutinised when evaluating options. Evaluation methods must be capable of capturing, quantifying and including such consequences if maladaptation is to be avoided.

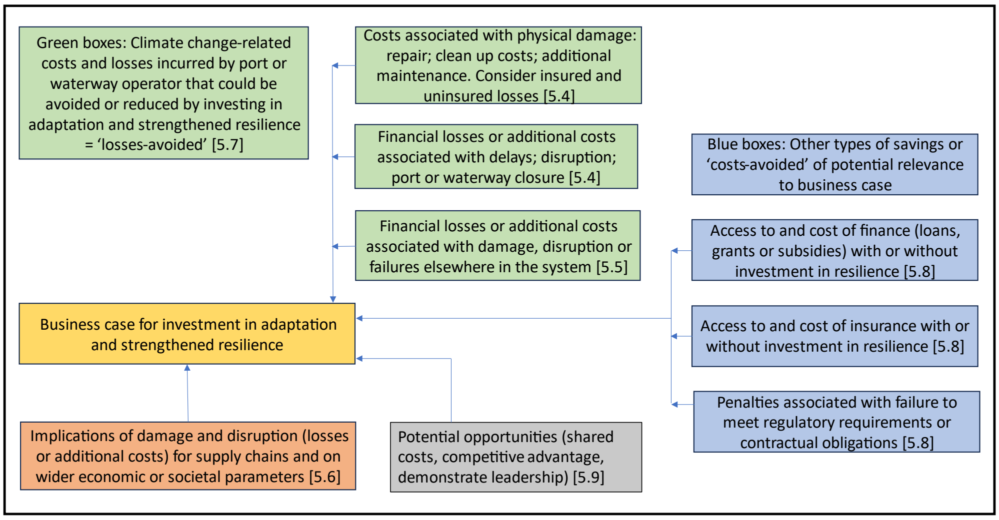
43. Methods that focus on maximising value rather than minimising cost are typically more appropriate to climate change adaptation decision making. Multi-criteria analysis, decision-tree analyses, iterative risk management, robust decision making, real options analysis, portfolio analysis or similar tools are capable of incorporating a wider range of considerations, to enable informed decision making. Several authors [Tröltzsch et al., 2016, DeFries et al. (2019), etc.] discuss the appropriateness of evaluation methods for selecting climate change adaptation measures. [THIS SIGNPOSTING NEEDS IMPROVING]

44. Understanding the consequences and costs of inaction helps demonstrate the benefits of expenditure on improved resilience. As mentioned above, avoided damage- and disruption-related losses represent a key benefit of investing in strengthened resilience. Recording the cost impacts of previous extreme weather events, or modelling and costing the impacts of such events, can help develop this understanding at asset or network level. Supply chain impacts and other cascading failures may be of critical importance to some operators, but can be challenging to quantify. The evolving expectations of the finance and insurance sectors with regard to the need for demonstrated resilience action, or the growing focus on climate risk reporting, may also be relevant to the process of justifying investment in adaptation.

45. Figure ZZ, from PIANC (2024), highlights the range of considerations of potential relevance to the adaptation business case. Ultimately, however, the nature of an organisation and its management or governance model, will influence both what should be included in an assessment, and the appropriateness of different methods to determine return on investment and justify expenditure.

18 PIANC, 2020
19 Refs needed in this para to PIANC suite of guidance
20 PIANC, 2020

Figure ZZ: Scoping the business case assessment for investment in adaptation and resilience



- Developing an adaptation strategy

46. The nature of an organisation and its management or governance model, will also determine the format and content of an adaptation strategy. Some organisations may be responding to a regulatory requirement or the demands of a financing institution. Others may be preparing a strategy to identify and reduce risks as a matter of good practice. This Chapter does not therefore prescribe what an adaptation strategy should look like, rather it focuses on the lessons learned from international experience in the transport sector to highlight what is likely to be relevant, important considerations, and some guiding principles for identifying and evaluating a potentially appropriate range of options. [IS THIS ACCEPTABLE, OR DO WE WANT TO TRY TO OFFER GUIDANCE ON WHAT AN ADAPTAITON STRATEGY SHOULD LOOK LIKE?]