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Database on adaptation measures

Guidance on adaptation pathways for the transport sector

Drafted by the University of Birmingham

I. Background

At its twenty-third session, the Group of Experts on Assessment of Climate Change Impacts and Adaptation for Inland Transport (GE.3) requested a group of volunteers to engage in the intersessional work to elaborate draft guidance on adaption pathways in the transport sector.

This document contains the draft guidance. It was drafted by Dr. S Anam Hashmi (University of Birmingham). Substantive inputs were provided by Dr. E Ferranti and Prof A. Quinn, (University of Birmingham), Ms. T. Popescu (France), Ms. C. Evans (PIARC), Ms. R. Burbidge (Eurocontrol) and the secretariat.

GE.3 is invited to consider this draft guidance and provide comments.

II. Guidance

A. Context and literature review on adaptation pathways

1. Introduction

Global climatic changes that are changing weather patterns are often a cause of extreme weather events such as record-breaking heat waves, extreme floods and storm surges. In the coming decades, global warming and the resulting climate change is anticipated to further increase the frequency, intensity, spatial extent, duration and timing of extreme weather events such as heavy rainfall, potentially causing unprecedented extremes. Over many areas of the globe, the frequency and intensity of heavy precipitation or the proportion of total rainfall from heavy rainfalls is likely to increase with continued warming in the 21st century. Mean sea level rise is expected to contribute towards the increase in extreme coastal high-water levels and projected precipitation and temperature changes imply possible changes in floods [1, 2].

Extreme weather events can damage and disrupt transport infrastructures in a multitude of ways. For instance, heavy rainfall events can result in flooding or landslides that cause road and rail closures or increase road congestion and the frequency of accidents. Road closures can also affect the evacuation of areas and can impact the ability for emergency services to access these locations affected. High temperatures can lead to various issues for railway infrastructures, such as failure of electrical equipment or track-buckling, which can further cause service disruptions. Overall, climatic changes such as increasing sea levels and temperatures along with growing intensity and frequency of extreme weather events (such as heavy rainfall and heatwaves) are threatening to compromise European transportation services and transport infrastructure. Such impacts on the transport sector can have destructive consequences and thus, transport infrastructure operators and owners must increase their preparedness by adapting to a range of hazards associated with climate change in order to reduce weather-related service disruption and subsequent financial costs. Future climate scenarios should be considered when installing new assets since transportation infrastructures have a design life of several decades (such as tunnels, tracks and bridges) in order to prevent unstable infrastructure or costly retrofitting. With existing assets and networks, these may need to be adapted to ensure that they are more robust in response to increasing climate hazards in order to continue providing and maintaining service provision and/or to avoid rising costs due to the consequences of extreme weather [3]. On the whole, as part of the climate change adaptation process and inherently improving resilience, transport infrastructure operators and owners must consider an uncertain future climate that may result in unknown impacts with unpredictable future socioeconomic situations for crucial transport infrastructure elements such as design, asset repair and management, business operations and continuity, emergency responses, and supply chain management [4].

Climate change adaptation plans and strategies must consider changes in magnitude or frequency of extreme weather events, long-term climatic changes, and anticipated socioeconomic shifts in population, technology, or governance [3, 5]. It is identified that many adaptation planning approaches can be focused on the cost-benefit analysis of individual local interventions, and may not be suitable for all applications due to the slow-onset nature of climate change events, particularly when combined with complex systems consisting of a mix of extremely long-life assets (for example, bridges) and short-life elements (such as digital systems assets) [3]. Sustainable development revolves arounds the topics of climate change and uncertain future conditions. Based on the complexity and uncertain nature of social-environmental challenges, planning approaches that promote adaptability must accommodate changing conditions over time.

Currently, there are several approaches available that are aimed at supporting decision-makers in dealing with uncertainty in long-term decision-making and emphasise the need for adaptability in plans in order to cope with deep uncertainty. Examples of such approaches include:

- **Adaptation pathways** - offer insights into the sequencing of actions over time, potential lock-ins, and path dependencies [6].
- **Adaptive policymaking** - offers a step-by-step approach for developing a basic plan, and contingency planning to adapt the basic plan to new information over time [6].
- **Scenario planning** - a practical technique utilised to inform decision-making under uncertainty, through the exploration of a range of future states and consideration of alternative response options [7].
- **Robust decision-making** - offers insights into conditions under which issues arise, and makes trade-offs transparent [8].

These approaches support choosing near-term actions, while allowing for possibilities to modify, extend or alter plans in response to future changes. Amongst all these approaches, it has been observed several times that the adaptation pathways approach is the one with several benefits, has an analytical approach unlike the adaptive policymaking method that is more of a theoretical approach, does not need much data like robust decision-making, and can be less time-consuming than other methods such as scenario planning that require the use of a high number of scenarios to be robust [6, 9]. The adaptation pathways method offers insights into the sequencing of actions over time, thus considering a large ensemble of transient scenarios

that for an extensive variety of uncertainties about future developments to be considered in the planning process. The approach includes trends and system changes as well as uncertainty due to natural variabilities. The adaptation pathways approach uses a fast and simple model that enables exploring several pathways over the ensemble, which can then be used to draft adaptation pathways maps [6].

Adaptation pathways offer a promising decision-focused approach that incorporates flexibility into decision-making and accounts for future uncertainties. Development of adaptation pathways and their implementation by infrastructure operators and owners can help adapt their current assets and networks to maintain current or improved levels of service and desired operational performance under future climate conditions. In a typical adaptive plan, adaptation pathways capture the implementation process by specifying which measure(s) are to be considered now and which are planned to be implemented once certain conditions (often defined with thresholds for climate variables) occur over time.

2. Adaptation pathways

Adaptation pathways can be broadly described as a sequence of interlinked and flexible actions that can be progressively implemented, based on future dynamics and changes to risk, through early actions that do not compromise future actions and assist in providing overall adaptation to climatic changes. These series of options combine long-term adaptation plans for a range of climate scenarios with short-term objectives and actions [3, 4, 10, 11]. Therefore, the adaptation pathways approach must be central to the option generation and analysis. It allows for adaptation to take place in stages or phases, where each phase can be planned and designed in a way that reduces the overall risk to an acceptable level as the climate or weather changes. In addition, contrary to a typical project management approach where each phase is planned to occur at a known and specific time, the phases in an adaptation pathways approach can be modified and implemented once the overall risk reaches a pre-determined threshold level [3].

With the application of the adaptation pathways approach to adaptation planning, it is possible to create a series of actions that can continue providing sustainable and efficient services as climate hazards develop into the future [12]. To elaborate, once a known action has reached its threshold level, another action can replace it to maintain the delivery of services while reducing any disruptions. These pre-determined threshold levels are usually set based on critical factors such as maintenance inspections, condition monitoring and medium and long-term weather forecasts, and they are defined through regular risk reassessments [3]. However, a key point to consider is the lead time needed to put actions into operation in order to ensure that any safety issues are not compromised. Understanding of the lead time allows planners to plan accordingly about how far ahead of a threshold being reached do they need to start preparing for introducing another action. Of course, such judgements can be prompted through the use of advanced monitoring systems and the use of climate indicators (such as the frequency of flood events). Therefore, the use and application of an adaptation pathways approach eases the process of identifying the point at which new adaptation actions are required along with assisting in pinpointing when to begin the lead-in process for implementing adaptive actions. Through such a tactic, it is highly likely that by the time actions are initiated, there is an increased confidence on when the threshold level will be reached, allowing for appropriate actions to be implemented. Also, such an adaptation pathways planning approach allows for the adaptation process to evolve at the same pace as the changing climate, without needing to know in advance what that pace or level of change is [12].

While the adaptation pathway approach helps improve long-term planning for climate change under future uncertainties, more local applications are important to understand the usefulness of the approach to asset owners and planners. From time to time, there may be instances that the hazard levels reach a point where current objectives cannot be accomplished beyond a certain level of climate change. For example, beyond a certain sea level rise, it might be determined that no further defences are feasible or affordable and thus the continuation of transport services in that particular area are no longer viable. In such cases, applying incremental changes shall be unfeasible and thus, a transformation change is needed, such as relocating the communities and rerouting the transport options. At such times of need, prior

understanding of threshold levels would prove invaluable as it can assist with planning to avoid further development in vulnerable areas and to develop inexpensive and effective options to meet new objectives [12].

3. Challenges associated with the adaptation pathways approach

Even though the adaptation pathways approach has multiple benefits, as discussed above, there are also some challenges associated with using this method that must be noted.

Indeed, with the implementation of adaptation pathways there is a lack of clarity in terms of the legal, financial and institutional implications of decisions and who would be responsible for associated impacts, costs and risk mitigation. This is a common issue with cross-jurisdictional funding and risk management structures. A study on overcoming cross-scale challenges to climate change adaptation for local government with a focus on Australia revealed that different councils respond to climate change and address planning in different ways. Without clear information on related jurisdictional responsibilities, the legal responsibilities remain unclear. Such a challenge could be overcome through the creation of a clearly defined mandate (that includes legal as well as political responsibilities), which results in a well-coordinated planning response. It should be clear as to who is responsible for planning for climate change impacts or the extent of the problem. Further, creating a consistent business case framework that utilises multi-criteria analysis points (such as cost benefit analysis) can assist with the documentation of necessary evidence for attracting and gaining political support that is needed for decision-making [13, 14].

Determining critical decision points such as adaptation tipping points, thresholds and triggers can be a difficult task under the different climatologic and socio-economic scenarios, especially for hazards that have a large natural variability (for example heat waves, droughts and storms). It is complex to monitor these hazards, mainly due to the lack of observations of extreme events. In the case of climate change induced changes in peaks or river discharge, monitoring data and further research has demonstrated that the natural variability in river discharge is so high that even when rapid (but not extreme) climate change is assumed, it can take 30 to 40 years before the climate change signal can actually be filtered in a statistically sound way from monitoring data of river discharge. Practically, to overcome such an issue, research is needed to find alternative approaches as well as parameters for filtering out the climate change signals from river discharge measurements. To accomplish such a goal, data-based detection of changes in observed events could be combined with exploration of possible future events through scenarios and modelling. Alternatively, large ensemble climate experiments might be able to offer a different approach to better quantify the changing probability of extreme events [15].

It is challenging to promote wider societal commitments in situations of low predictability. Adaptation pathways make it clear as to what measures should be taken in the short-term and sketch possible future measures applicable for longer term. With regards to the future measures, the decision to implement them may not be taken till there is certainty about future physical conditions (such as the happening of dramatic events) taking place. This implies that societal anticipation to adopting these measures is hindered. For example, water supply may become limited at some point in the future, but the dependency on this limited resource is unpredictable, and this may lead to either an increased demand in the short term or a slower adoption of newer solutions and technologies. Overall, the delay in taking the final decision for the implementation of the measure can either be a net advantage or a net disadvantage depending on the nature of the measure. Therefore, it is recommended that possible trade-offs are considered in planning the right time for making the final decision about the actual implementation of the measure [15].

The range of adaptation pathways may be too narrow if there is limited stakeholder engagement, resulting in a compromise on the full potential of the pathways approach. For an adaptation pathway approach to be successful in revealing what is required for more transformative forms of adaptation, whilst focusing on ecological and social dynamics, and enabling actors to learn together to create solutions, it is important that a wide level of stakeholder engagement is observed. Essentially, stakeholder involvement needs to be front and center when the adaptation challenges are diagnosed and objectives are defined [14].

B. Summary of commonly used expressions for adaptation pathways

A number of academic-practitioner groups have brought a great wealth of knowledge in developing concepts on adaptation pathways. Table 1 provides a list of some commonly used expressions and their relevance in describing and discussing the adaptation pathways approach, based on the views of different groups of researchers and practitioners. It is expected that transport professionals can benefit from these expressions and their explanations to better understand the guidance provided in this paper.

Table 1
Summary of some commonly used expressions and their relevance in discussing adaptation pathways

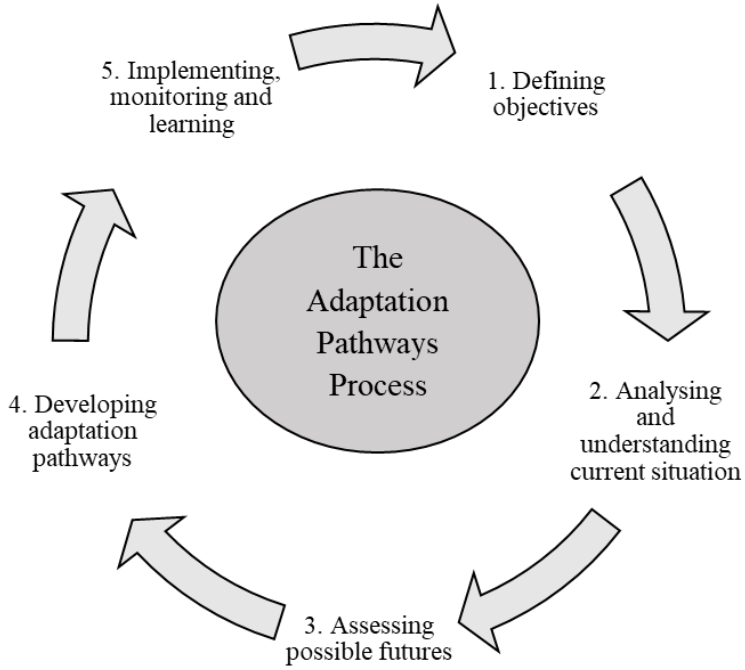
Expression	*Explanation*
Adaptation	Adaptation in the context of climate change refers to responses that reduce the negative impacts of a changing climate, while taking advantage of potential new opportunities. This can include making adjustments to economic, social or ecological systems in response to current or anticipated climatic stimuli and their effects [16].
Adaptation measure	A specific action implemented to reduce the impacts of climate change or to increase adaptive capacity [16].
Adaptation option	A mix of measures taken to reduce the impacts of climate change or to increase adaptive capacity [16].
Adaptation pathways	A sequence of interlinked and flexible actions (adaptation options) and decision points that can be progressively implemented over time, to address impacts from climate change, based on future dynamics and changes to risk [4, 16].
Adaptation pathways map	A graphical representation of adaptation pathways.
Adaptive capacity	The ability of systems and institutions to adjust to potential damage, to take advantage of opportunities, or to respond to consequences of impacts of environmental variability and change. It includes adjustments in both behaviour and in resources and technologies [16].
Adaptive policies	Policies that address changes over time and make explicit provision for learning [18].
Adaptive management	A systematic process for repeatedly enhancing management policies and practices through learning from the outcomes of operational programs [19]. Adaptive management strategies can support planners and managers seeking to overcome the inherent uncertainty surrounding climate change, its impacts and find appropriate responses [20].
Cascading impacts	Impacts arising when extreme weather/climate events occur where an extreme hazard generates a sequence of secondary events in natural and human systems resulting in, natural, social, physical or economic disruptions, where the resulting impact is expressively larger than the initial impact [16].
Climate Indicators / Trigger / Signposts / Thresholds	Often referred to as thresholds, Adaptation Tipping points, or triggers, these are embedded within developed pathways to symbolise when a management strategy is no longer viable and a different adaptation strategy must be implemented. It must be noted that is contrary to the concept of switching to different pathways based on arbitrary time periods (such as 5 years), with no fundamentals in the likelihood of environmental risk [4, 10].
Deep Uncertainty	Type of uncertainty where stakeholders and decision makers do not know or find it difficult to agree on how likely different future scenarios are [21].

Expression	*Explanation*
Decision points	Often occurring before a threshold or use-by-date, these are points in time where progress reviews as well as alternate response choices need to be made [16].
Interdependencies	Climate change related interdependencies refer to the interconnections between various climate risks (such as increasing temperature and reducing precipitation that will impact the availability and quality of critical resources), which then have an influence on various sectors (such as energy). Also, modern urban infrastructure systems are highly interdependent, formed of multiple connections, feedback and feedforward paths, and intricate branching. This indicates that if one system fails, it can result in cascading impacts on other systems (for example, a power failure can possibly have an influence on railway operations) [22].
Levels of risk (acceptable or unacceptable)	Adaptation pathways are designed based on acceptable or unacceptable levels of risk. A pathway switch is needed when the level of risk is no longer considered acceptable, as indicated by an environmental indicator. Usually, stakeholder perspective or an occurrence of extreme weather event determines the acceptable level of risk [4, 23, 24].
Maladaptation	Actions and responses to climate change that may demonstrate short-term adaptation in one key decision-making area but may have determinantal and negative outcomes in other areas or even the same area in the longer-term [16].
Multi-criteria analysis (MCA) or Multi-criteria Decision Making Method (MCDM)	An effective and convenient decision-making tool that can address an extensive range of sectors, combine costs and benefits along with other qualitative options [25].
No-regret, low-regret and win-win options	• No-regret actions are cost-effective adaptation actions applicable for existing climate conditions and are consistent with addressing climate change risks. These actions have no hard trade-offs with other policy objectives. • Low-regret adaptation actions are fairly low-cost and offer comparatively large benefits for predicted future climates. • Win-win adaptation actions contribute to adaptation at the same time they also have other environmental, economic and social benefits [26].
Resilience	The ability or capacity of social, economic and environmental systems to cope with a hazardous or disruptive event, responding or reorganising in ways that maintain their essential functions, structures and services while also being able to maintain the capacity to adapt, learn and transform [16].
Threshold	The point at which a system begins to function in a significantly different way. Thresholds can be physical, environmental, economic or social [16].

C. Prerequisites for the development of adaptation pathways

While this guide is intended to provide guidance to transport infrastructure asset owners, operators and managers on developing adaptation pathways, there is a certain expected level of knowledge and understanding that is needed to fully comprehend the guidance and thereafter implement it. Essentially, the development of adaptation pathways is a part of a simple 5-step cyclic process, as shown in Figure I.

Figure I
The simplified five steps of any typical adaptation pathways planning process (Adapted from [27]).



The first step in developing an adaptation pathways approach is similar to other planning processes, which is to define the objectives, targets and goals as well as including key indicators that can be used to assess success (i.e. whether or not a goal has been reached). This first stage requires the transport infrastructure owners and managers to determine what they want to ultimately achieve and is therefore a crucial initial step as not defining properly or incorrectly setting the objectives can usually have an influence on all the proceeding planning stages, thus impacting the produced adaptation pathways. Thus, objectives should be specific, measurable and time-framed, while relating to an overall goal. Objectives are likely to be revised, changed or even abandoned over time. The framework described in section 4 expects that this step or stage is already carried out by the relevant transport infrastructure owners and managers who are interested in developing adaptation pathways for their assets [27].

However, to enable an efficient application of the adaptation pathways framework, objectives should be defined relatively to a level of risk, since the adaptation objective is likely to differ based on the risk level [28]. In the first phase of defining objectives, before stepping into the actual framework and defining risk levels more precisely, it is best to define risk levels in a qualitative way, for instance as low, medium and high. For example, a railway infrastructure manager could define gradual levels of service to maintain their railway infrastructure depending on the risk level, intending for all trains to be able to run at a low risk level, whereas only the most important rail links may need to run at the highest risk level. Likewise, a higher travel time could be accepted on the same infrastructure for higher risk levels.

The next step of adaptation pathways planning approach is analysing and understanding the current situation. Of course, each asset or infrastructure is unique in terms of its characteristics and the services it provides. Thus, knowing as much as possible about one's asset or infrastructure, can provide a good foundation for analysing potential future situations and ultimately for developing relevant adaptation pathways. It is recommended that with the ultimate goals in mind, the current situation is assessed to set environmental, social and economic baselines. This starting point will help assess the results of a scenario where there is no change and will thus help envisage possible futures [27]. Therefore, it is important that transport infrastructure asset owners and managers carry out this step with due diligence, possibly through in-depth consultations within their organisations to gain a full extent of knowledge so that they have a good understanding of the requirements of this stage for their individual assets. To do so, they can analyse historical information and drivers that have

resulted in the current conditions and assess how the asset has been managed or what all has been done or what actions have been taken to solve the current problems. This information should be used to design and develop potential future management actions. However, one key point to consider is that historic information is not always enough.

Transport planners and operators usually consider the impacts of past extreme weather events. Recent work in Europe has indicated that several standardised approaches for factoring extreme weather parameters into the design of transport infrastructure are still applying historic weather data that is already out-of-date. Over the past two decades, the climate has changed severely and thus, the historical weather data can no longer fully reflect the current climate risk, let alone the way climate risks will change over the useful life of a transport system. Some critical transport infrastructures such as bridges have long lifespans and thus, it is now recommended that full asset lifecycles are considered in climate adaptation. It is vital that climate change scenarios and their implications for average and extreme precipitation and temperatures along with the likely frequency of extreme events in the future is accounted and implemented in all stages of design and implementation [12].

The third step of adaptation pathways planning approach is to analyse, develop and assess the possible future scenarios. This stage builds on the previous stage and is informed by climate projections to predict the state of the environmental, social and economic factors in the future. Projected future scenarios can then be tested against different options to understand if they are desirable options or not. Overall, this stage can be very helpful in developing various management responses and thus acknowledging other factors that influence a management response, such as market and social values or future policies is very important. Regardless, it must be noted that the future is always going to be uncertain but through the development of a range of scenarios, several different options can be tested and determined if they are flexible, robust, or both [27].

Overall, as part of the second and third stages of an adaptation pathways planning approach, understanding of the current situation and possible futures should be used to determine management actions that may lead to reducing the vulnerabilities and/or increasing the adaptability for the individual assets. Also, evidence-based, robust, ‘no-regret’ options should be identified here as it can enable organisations to implement short-term adaptation actions and commence the adaptation process, instead of waiting and analysing the situation [26]. Nevertheless, stages 2 and 3 should help in informing how a pathway approach may be best developed.

The fourth and fifth steps of adaptation pathways planning approach are to develop the pathways and implement, monitor and learn from them. These steps will be discussed in-depth in the next section. However, it is expected that the transport infrastructure owners and asset managers have a good understanding of the first three stages in order to appreciate and implement the findings of the information provided in the next section. Of course, the former could be a challenging task in itself and thus it is recommended that transport infrastructure owners and asset managers encourage stakeholder engagements, encourage the inclusion of experience and tacit knowledge to ensure that the acquired knowledge/skill set aligns with the existing management approach, and the specific context and asset portfolio [4].

It must be remembered that transportation systems are interconnected and complex systems that can have changing patterns of ownerships, operational control, use, a variety of asset ages and lifespans along with the ability to be further engineered and developed over time. Hence, a number of potential interventions and methods are required for the adaptive management of transport networks in order to assess their effectiveness and phasing over time. The idea of a risk-based, circular approach, where interventions are planned, implemented, monitored and assessed as the initial phase for new action planning is now increasingly becoming accepted. In this regard, some national transport authorities such as Trafikverket, Sweden, and several international bodies such as PIANC have recently started to show developments in their adaptation strategies [3]. Additionally, the PIARC Climate Change Adaptation Framework, 2015 is currently being updated to incorporate adaptation pathways as an approach for assessing deep uncertainties, and as a continuous process of assessing and implementing adaptive measures as new information and changing circumstances arise [29].

Further, this guide suggests that transport infrastructure owners and managers who are interested in developing adaptation pathways must also have a detailed understanding of the vulnerabilities of their individual assets and should have performed the appropriate risk assessments on their individual assets. They could possibly use risk assessment frameworks that have already been developed and recommended by organisations such as PIANC (World Association for Waterborne Transport Infrastructure), PIARC (World Road Association) and similar. This could be carried out as part of the steps 1–3 highlighted above. As part of step 2, transport professionals should understand the risk and opportunities that exist from the current climate. This would include comprehending the environmental factors that affect the current systems as well as identifying what the most critical issues are. Transport infrastructure owners and managers should then look into what decisions that affect these risk and opportunities do they have / not have control over. This approach should then be carried out for a range of future climate scenarios (possibly as part of step 3). This would include understanding the high and low probability climate scenarios. The localised and systemic implications as well as an assessment of what could fail on a pathway towards a particular scenario must be assessed and understood [4].

Certainly, as part of the risk assessment, identifying the current climate hazard, the vulnerabilities and adaptive capacity is essential for effective adaptation planning. This can be done by reviewing and analysing the level and nature of changes in the climate hazard and vulnerability which would need to be managed over the useful life of the transport system or asset. It must be noted that for identifying appropriate adaptation options, it is crucial to understand the fundamental nature of a risk and its root causes. For the analysis of vulnerabilities, climate impacts on transport can be distinguished as:

1. Impacts on transport infrastructure and rolling stock
2. Impacts on operations and level of service provisions, including supply chains
3. Impacts on mobility behaviour, patterns and demand
4. Impacts on health/wellbeing of passengers and personnel

Transport professionals should have a good understanding of the environmental, physical, social and organisational elements to deliver mobility for people and goods in order to fully grasp the overall vulnerabilities. Also, the vulnerabilities need to be considered along a range of different levels of climate change impacts in order to find a way to most effectively respond to them. This includes identification of the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variables and extremes. According to PIARC [29], vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed (existing or future exposure); and the degree to which infrastructure is affected, either adversely or beneficially, by climate-related stimuli (sensitivity). Vulnerability is therefore where a climate hazard may lead to an impact and evaluation of what is a tolerable risk level as part of the overall vulnerability assessment. Thus, it is vital to consider both, the vulnerabilities from direct impacts on transport systems and the resulting cascading effects such as the further impacts on the services or the infrastructure upon which the system depends. For example, power (electricity) supply for electric vehicles and their supply chains. As part of conducting the vulnerability assessment, it is essential that factors such as climate change scenarios, risk levels, thresholds and interdependencies are also considered carefully [12]. The PIARC Framework notes that, a vulnerability assessment is expressed as a function of three factors that can be combined in various ways to assess vulnerability, comprising exposure, sensitivity and adaptive capacity (or ability of the system to successfully respond to climate change), according to available information (e.g. use of quantitative, semi-quantitative and qualitative information tools) [29].

Moreover, analysis of the system and how it has performed during extreme weather events in the past can help offer insights into potential future vulnerabilities. This analysis can be carried out based on traffic incident reports, maintenance records, after-action reports, emergency reimbursement forms and cross-departmental interviews [30]. Overall, it is important that transport professionals use this step to identify ways to address the existing drivers of vulnerabilities of the transport and related infrastructures under current conditions. It has been suggested several times in the past that adaptation is most effective when both,

the root causes and the symptoms of vulnerabilities are addressed, specifically in those situations where practices and goals need altering as they are either no longer suitable or needed under the changing climate, and thus transformational adaptation is needed [31].

D. Framework for developing adaptation pathways for transport professionals

This section provides and discusses an adaptation pathways framework (as shown in Figure II) suited for use by transport infrastructure owners, managers and operators to structure short- medium- and long-term climate preparedness planning.

An effective adaptation planning begins with the identification and prioritisation of options based on the risks/vulnerabilities identified by the climate change risk assessment and builds on chosen scenarios that reflect the projections on climate change and address stakeholder concerns and issues. The development of adaptation pathways will often involve a mix of approaches, mainly depending on the scales and complexities of the set goals and objectives and thus may require multiple iterations. The two deciding factors when selecting a mix of approaches will be the degree of certainty of present information and knowledge and the agreement on goals within the transport sector [32].

It must be noted that any potential adaptation option should be assessed in terms of its robustness and flexibility with respect to the range of potential futures expected. Potential tipping, turning and trigger points should be identified at this stage based on the current situation and possible futures analyses. Also, the aim should be focused on identifying alternative options to achieve objectives so that stakeholders in the transport sector can justify, prioritise and implement actions that take climate change and associated changes in economic, socio-political, knowledge, values and ecosystems into consideration. Additionally, in the adaptation planning process and the development of adaptation pathways, consideration of the geographic scale at which adaptation responses are needed is very important. For example, the geographic scale on which pathways are formulated can range from a small coastal stretch to perhaps a large delta area with different land uses and drivers of change. Also, the geographic scale can also help determine the relevant stakeholders and sectors that might be included in the development process, which then further determines the generation of options. One case study demonstrated that a mismatch between geographic and institutional scales resulted in fuzzy thresholds, a large array of options and unclear institutional responsibilities [33]. An important consideration involves capacity building through developing and sharing information, resources and decision-making tools for adaptation measures; community sharing and understanding on the need to adapt, and collaborating with the community to achieve agreed responses [34].

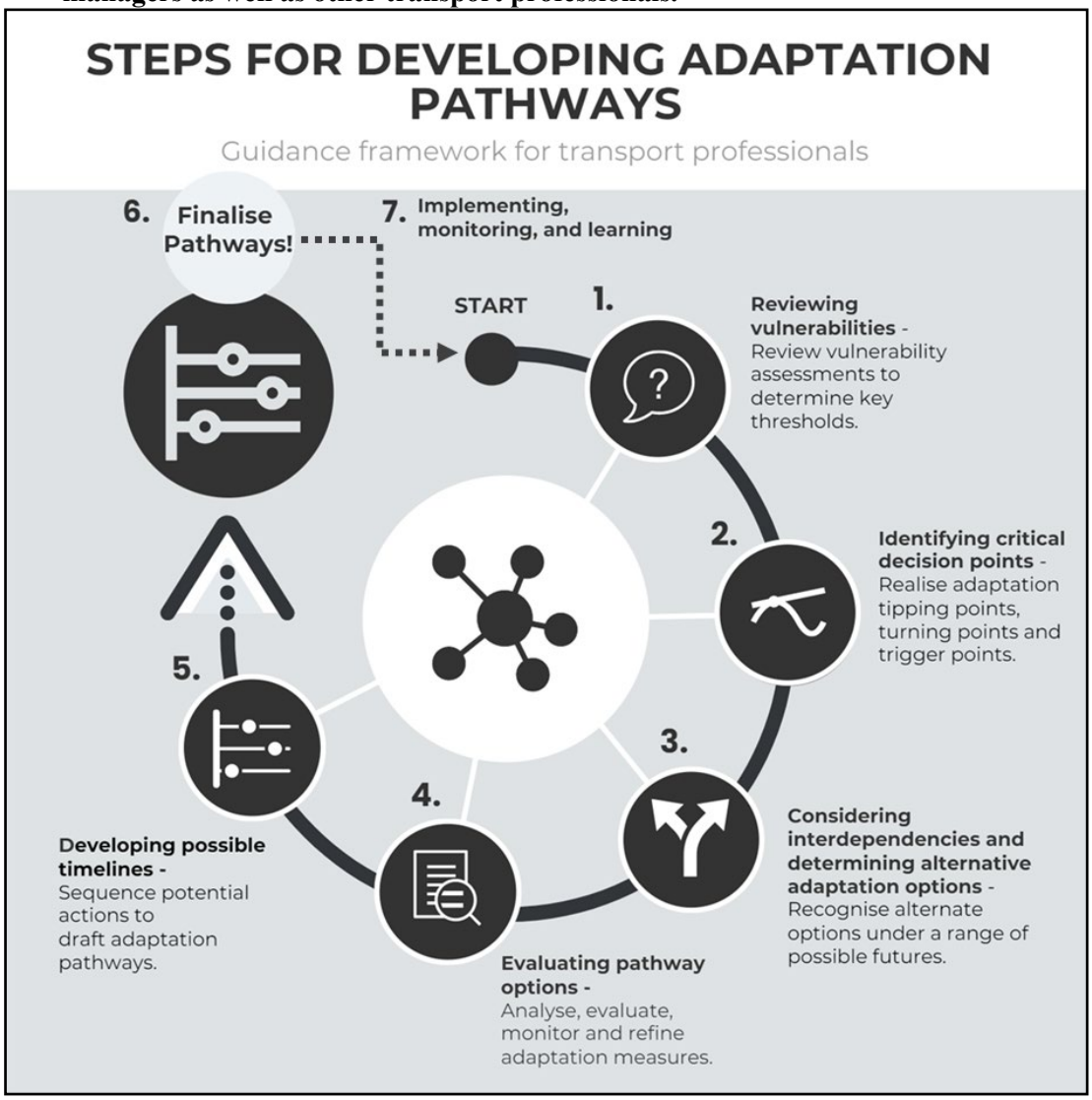
1. Guiding steps to develop adaptation pathways for transport professionals

To develop adaptation pathways, there is a certain expected level of knowledge and understanding that is needed from transport infrastructure professionals and is discussed in Section 3. This is important to fully comprehend the guidance and thereafter implement it. This section elaborates the steps 4 and 5 shown in Figure I. For any particular goal or objective, the development of adaptation pathways is expected to broadly follow the following steps:

1. Reviewing vulnerabilities
2. Identifying critical decision points
3. Considering interdependencies and determining alternative adaptation options
4. Evaluating pathway options
5. Developing possible timelines
6. Finalising and visualising adaptation pathways
7. Implementing, monitoring and learning

Figure II

Steps for developing adaptation pathways for transport infrastructure owners and managers as well as other transport professionals.



(a) Reviewing vulnerabilities

The development of adaptation pathways commences by the identification of what is presently being done to manage systems and issues related to the particular objective. Ongoing practices are usually in place for particular weather events and climate patterns, depending on the current and historical times. These practices have existing management strategies which have their own strengths and vulnerabilities. Over here, this step entails reviewing and revisiting the vulnerability analysis of key infrastructures to understand about the existing vulnerabilities and to determine thresholds which can help identify additional actions that may be needed to address the objectives within existing constraints [32]. Looking at the current or baseline capabilities (i.e. to assess the technical and the institutional capabilities for responding to climate and extreme weather) is an important step which must be carried out prior to seeking improvements in those capabilities. Also, investigating previous vulnerabilities can mark as a suitable starting point for addressing future vulnerabilities. This step could help determine and assess the key thresholds (such as sea levels or embankments and their performances) between the current vulnerability and maximum climate driver (such as sea level rise). Some common examples of climate change related vulnerabilities for the transport sector include [30, 31]:

- Risk of physical damage to the height, slope and materials and overall integrity of structures

- Loss of roadway capacity
- Loss of alternative routes or situational awareness
- Loss of service life (perhaps due to faster deterioration of the design life of the infrastructure)
- Loss of economic productivity
- Decreased mobility
- Reduced safety.

Guiding and learning questions for transport professionals for reviewing vulnerabilities.

What kind of diagnostic methods can successfully map root causes of vulnerability and controlling variables, particularly across scales?	What is currently being done, and what else could be done, to produce specific outcomes under the present conditions?

(b) Identifying critical decision points

Adaptation pathways begin with current management options. These management options can be affected by the potential implications of climate change. Such implications for both the system being managed and current management options inform where decisions should be made. Existing management options can be considered in a range of possible futures, which then helps in addressing the next step. Through combination of information from the current situation and future analyses, it becomes possible to identify probable thresholds or tipping points and turning points for adaptation options [32]. Those thresholds are defined through indicators which enable monitoring risk levels. Indeed, the thresholds need to be associated to the levels of risk used to defined the adaptation objectives [28]. Each risk level can then be quantified based on those thresholds.

Adaptation Tipping points identify thresholds where magnitude of change because of climate change consequences (such as flooding events) exceeds the present capabilities of the management strategies to meet current objectives. Thus, with the identification of tipping points, it is possible to understand whether and when a management strategy may fail and other strategies will be needed. Also, with adaptation tipping points, it becomes possible to understand how much climate change can the system cope with using current practices [32]. An example of identifying adaptation tipping points in the context of coastal defences for vulnerable coastal transport infrastructure was made by determining the level of sea-level rise at which the defence is no longer able to meet its defined performance threshold [35]. In terms of transport infrastructures, weather-proofing these may need a high initial investment, however, over the longer-term this is a necessary step in order to prevent the escalating costs or even expensive retrofitting. In such cases, it is vital to identify the tipping point at which the cost of additional adaptation becomes disproportionate to the added benefits achieved [3]. Overall, potential tipping points for transport infrastructure and assets can be identified through conditions under which:

1. Action(s) may no longer be effective,
2. Asset or system thresholds might be reached, and
3. Asset or system might change (probably due to climate changes)

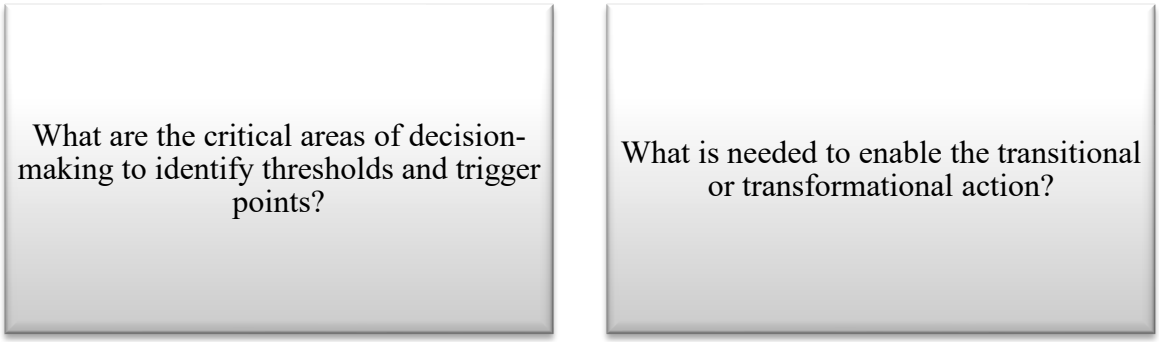
Adaptation Turning points indicate situations in which a social-political threshold is reached. This may be due to changes in climate, social values and interests or policy objectives [32]. A case study on the flood safety and nature conservation at Wadden Sea in Netherlands revealed that with review of policy documents, it becomes possible to identify social-political thresholds. For the identification of the climatic conditions for reaching thresholds, the case study made use of literature reviews and expert consultations on issues such as sediment behaviour, sea-level and storm surge dynamics in relation to the coastal defences. To identify when turning points are reached, risk assessments were used based on the opinions of experts and harmonisation of existing literature. Finally, identification of a turning point for the Wadden Sea helped interpret and integrate the results [36, 37].

Trigger points mark the beginning of necessary lead time for an action before reaching a turning point. Trigger points can be defined by how long a decision to change takes to be made and implemented. The latter originates from the next stages of identifying alternative options. Overall, trigger points are a crucial element in the development of adaptation pathways approach, allowing for plans to be anticipatory and strategic. The trigger for an adaptive action in one part of the transport system may be a threshold reached in another part of the system [12, 32]. Also, positive trigger points can also be identified for possible opportunities such as: political will and readiness of additional funds.

In adaptation planning, the idea of thresholds is quite common, however requires special efforts to apply. For transport professionals, the concepts of thresholds are relevant in understanding when managers need to change from one response option to another. Thresholds can be defined as points at which a system starts to operate in a significantly different manner. In the transport sector, a threshold can be defined as a set of climate conditions under which a part of the transport system is no longer effective, either in terms of economic, environmental, physical or social aspects. Thus, at that point, a further adaptation measure is needed. For instance, due to a certain threshold level of windspeeds, traffic for heavy-duty trucks at a bridge may be required to be stopped to prevent the destruction of the bridge. In such a case, if alternate routes are possible, an example of an adaptation option would be to divert truck traffic. Furthermore, in extreme cases, such as at a much higher threshold level of windspeed, the bridge infrastructure may be damaged and thus in such a scenario, adaptation of the physical infrastructure to secure serviceability will be needed [12].

Triggers may occur without a threshold being reached and should be easily monitored to enable prompt action. It must be noted that thresholds and triggers have different meanings. For example, at a particular location, an increase in sea level may indicate a large storm which can possibly destroy infrastructure. In such a case, even if this has not occurred in reality, a threshold would be the actual failure of the that infrastructure involved and contributes to a real change in system function. The trigger in this example is the rise in sea level reaching a point at which a decision needs to be made, even though the trigger may not have caused the threshold being crossed [16].

Guiding and learning questions for transport professionals in identifying critical decision points.



(c) Considering interdependencies and determining alternative adaptation options

In the development of any adaptation pathways, one important step is the identification and consideration of alternative adaptation measures and thereafter adaptation options to help address the objectives defined relatively to different risk levels. For each adaptation measure identified, it is important to determine to which adaptation goal it leads. A same action can lead to several adaptation goals, or only one or some of them [28].

To identify adequate adaptation measures, an important element to consider is the interdependencies with other drivers, especially for the transport sector [4]. Modern-day transport infrastructure facilities and processes are intricately dependent on each other. This creates a network of highly critical functional units that can cause massive unintended consequences which can have safety and economic implications even if one is compromised by hazards caused by issues such as climate change. Transport infrastructure owners and managers must identify and understand the critical interdependencies between their infrastructure and other infrastructure networks (such as energy supply, road transport), as this will be crucial for continuing work on climate change adaptation planning. This includes the consideration of potential cascading failures between interlinked natural and socioeconomic systems and sub-systems. For example, a period of prolonged and widespread severe weather can affect the transport network which may then have an impact on the availability of and access for transport personnel (such as lorry drivers), compromising vessel loading and unloading efficiency, and creating a backlog that ultimately affects the wider supply chain. Alternatively, a power outage may affect the safety and function of the transport operations and services. Also, transport departments not expected to suffer from a particular climate risk can also be expected to suffer at some point due to interdependencies and therefore indirect impacts. Thus, the transport sector must be fully resilient to climate change and including the interdependencies element in climate adaptation planning and developing adaptation pathways can be a key entry point for a more holistic approach to enhancing resilience.

The identification of critical decision points (tipping, turning and trigger points) is then the main tool to help recognising what options can be useful in avoiding, limiting, or removing the climate change impacts as well as other environmental, economic and socio-political factors. These actions need to be reviewed in order to determine what triggers could make them necessary and to also examine if they are robust across possible futures (see section 4.1.5. about the evaluation of adaptation actions). It is understood that identifying new or alternative options can be a challenging task and thus it is best to have a diverse, creative and constructive participation and collaboration to raise, discuss and consider unusual elements [32]. Thus, the guiding questions for transport professionals to think here are: How does an option contribute to achieving the objectives or goals? and what are the roles of the relevant stakeholders, including transport sector organisations?

The adaptation actions can be of many kinds: they can be technical, legal, or institutional, can imply to increase knowledge, raise awareness, or to communicate about specific impacts of climate change [28]. It can be useful to identify to which of those categories the identified action belongs, and to seek actions from various categories in order to ensure various adaptation pathways possibilities. It is also advised to define whether an adaptation action is an adjustment (for instance, a modification of a current infrastructure, using a road paving more resilient to heavy rains) or a transformation action (for instance, relocating an infrastructure threatened by rising sea levels). Furthermore, this guide recommends transport professionals to make use of various useful resources such as the WEATHER [38], EWENT [39], MOWE IT [40] and SIRMA [41] project deliverables as well as online databases such as Copernicus [42] and The European Climate Adaptation Platform Climate-ADAPT [43] to explore what adaptation measures and options are currently being used in the transport sector.

According to PIARC [44], adaptation measures can be defined as:

- Infrastructure related hard measures (e.g. barrier walls for protection from erosion, levees, alternative surfacing), and also involve the use of soft measures (e.g. creation of wetlands, barrier islands, green infrastructure to cope with high precipitation events);

- Traffic hazard/incident management measures such as establishing well-prepared command and management structures, providing appropriate information systems or training personnel for managing catastrophes, early warning systems or traffic re-routing;
- Maintenance measures for periodic, routine or self-restoration;
- Strategic and network planning measures e.g. amendments to regulations or standards, legal frameworks.

Guiding and learning questions for transport professionals in considering interdependencies and identifying alternative adaptation options.

How does an option/action contribute to achieving the objectives or goals?

What are the roles of the relevant stakeholders, including transport sector organisations?

How to best combine activities varying from physical interventions to capacity-building and governance arrangements into the development of pathways to create and support the transformational changes needed?

What steps are being considered currently to address the critical and important areas of decision-making?

Will climate change influence the success of measures being considered to address key areas of decision-making? If yes, which aspects of the changing climate are important and how long witll the current practices remain successul for?

(d) Evaluating pathway options

As with all transportation budgeting processes and any planning process, it is not possible that departments of transportations can fund their entire preferred list of adaptation strategies. Therefore, in order to narrow potential options, it is useful to utilise a systematic evaluation process. The following criteria or questions may prove useful as a starting point for evaluating and selecting adaptation measures [30, 32] in adaptation pathways.

Guiding and learning questions for transport professionals in evaluating and selecting adaptation measures.

Costs and Benefits – What are the up-front costs of implementation and the ongoing operations and maintenance costs? If implemented, what is the value of the damages from climate change that would be avoided?
Will there be any co-benefits (such as biodiversity gain, climate mitigation, etc.)?

Technical and Political Feasibility – How practical it is for a particular strategy to be implemented, accounting for engineering, policy, legal, and insurance considerations?

Flexibility – How easy would it be to revise the strategy at a later date? What is the adaptive management potential of the strategy?

Sustainability – What are the impacts to the economy, society, and the environment?

What are the synergies with other actors (does the action improve the adaptive capacity of other sectors?)?

What are the climate mitigation contributions?

Efficacy – if implemented, to what extent would the strategy reduce the risk?
Will the strategy make sure it does not put new constraints on physical, socio-political, financial, or social systems?

Maladaptation – Will the strategy ensure that it does not create a 'dead-end' by impacts on other assets, infrastructures or values?

Social acceptability – What is the outcome of a collective judgment or collective opinion regarding the strategy?

Potential options need to be evaluated for costs, benefits, technical and political feasibilities, flexibility, sustainability (environmental benefits, contribution to climate mitigation, increasing the adaptability of other sectors/transport infrastructure), efficacy, social acceptability and the ability to avoid maladaptation [4, 28]. This can be done through a multi-criteria analysis, using different weights for the different criteria. For instance, a higher weight could be used for the cost-benefit criterion in order to prioritise the measures with the smallest overall cost. The idea over here is to determine what methodology and what effort level would suit best to the needs of the organisation. Along with considering cost-benefit

analysis and multi-criteria analysis, this may also include participation, modelling and co-creation with potential stakeholders [4].

In terms of co-benefits of adapting, it is very important that transport departments identify and account for the possible benefits as well as co-benefits of integrating particular adaptation strategies into the management of transportation systems and operations programs. Usually, a qualitative assessment of co-benefits helps in identifying win-win strategies that can enhance resilience to climate change along with assisting in achieving other program objectives. Typically, it is also easier to acquire support for funding such types of solutions as they can achieve several goals. One common example here is the upsizing of culverts, often justified by departments of transportation as the benefits include the increase spaces fish passages as well as the increased capacity offered for increases in future extreme precipitation events. Some other prime examples of co-benefits include: increased roadway safety, reduced operating costs, mitigation of greenhouse gas emissions, improved air quality, sustainability through improvements to environment, economy and/or social equity and overall improvements in other performance measures [30].

Furthermore, to assess the sustainability of adaptation options for the transport sector, it is very important that mitigation implications of investments are considered carefully. Universally, the transport sector is accountable for around one-quarter of energy-related carbon emissions, which does not include the lifecycle emissions of construction materials. The use of cement only is accountable for about 8% of carbon emissions. Thus, it is vital to take into consideration the embodied energy and emissions of construction materials used in transport projects. Also, the mitigation and adaptation implications of the wider transport networks should also be recognised [12]. Moreover, in the transport sector, evaluation of adaptation measures can be done qualitatively and/or quantitatively, mainly depending on the needs of an individual organisation. For most transport departments, a qualitative assessment is usually sufficient when choosing priorities, however, in order to justify funding sought, a quantitative assessment may be needed. For a qualitative evaluation a simple 3-point (i.e. low, medium, high) or a 5-point scale can be used or even in some cases, a narrative description of the positives and negatives of the adaptation strategies can be relied upon. On the contrary, an effective quantitative evaluation requires the demonstration of benefits in quantitative evaluation metrics such as reduced traffic delay, which can then be translated into further financial benefits in the economic assessment of the strategy [30]. Although such metrics are a useful tool in informing the decision-making processes, it is important to remember that these should not be relied upon wholly and should not be the basis for the entire decision-making process. During the strategy selection process, it is important to also consider inputs from staff who are involved on the respective projects on a daily basis as well the relevant stakeholders and decision makers who probably have a better understanding of the needs. In addition, it is also suggested that the total number of evaluation measures are kept to a small set of valued measures to enable meaningful outputs to be generated [30].

In terms of prioritising measures, it is important to consider implementation time frames. Adaptation measures can be prioritised into short-term (such as 0-5 years), medium-term (such as 5-10 years), and long-term (such as 10+ years) actions, depending on the urgency of adaptation (i.e. how soon does the strategy to protect the asset or infrastructure against the projected climate changes need to be implemented by the transport infrastructure manager) and the time needed for implementation (i.e. how much time it will take for the adaptation strategy to be implemented based on the plans, funds, and construction/programming time). In this regard, Table 2 presents some typical examples that can be used to further understand the concept of how implementation time periods and the level of urgency could be factored into prioritising any adaptation measure [30].

Table 2
Generic examples demonstrating typical relationships between the prioritisation of adaptation measures and the implementation time, level of urgency and multi-criteria analysis (Adapted from [30]).

Adaptation measure	*Time Period for Implementation*	*Level of Urgency*	*Multi-criteria analysis*	*Prioritisation*
Requires 0-5 years to implement, but does not need to be undertaken for another 30 years	Short	Low	Low	Low
Requires 0-5 years to implement, but should be undertaken now in order to be effective	Short	High	Medium	Medium
Requires 30 years to implement, but should be undertaken now to ensure effectiveness	Long	High	High	High
Should be undertaken in the near term because it will influence future decisions	Ongoing	Medium	Medium	Medium

When considering implementation timeframes, it is also important to analyse the necessary anticipations for each adaptation measure, such as the acquisition of a technique, of knowledge, or the need for communication, or urban planning. The goal is to identify when actions need to be launched to ensure long-term robustness, considering the adaptation tipping points, turning points and trigger points.

After the individual evaluation of each adaptation measure, actual adaptation pathways, consisting of feasible sequences of adaptation options need to be designed, so that the pathways are also evaluated. This evaluation can be based on the same criteria as for the actions, especially including the cost criteria.

Additionally, transport professionals should also consider the current repair and replacement cycles for their infrastructures prior to implementing any stand-alone projects. Usually, proactive measures are sensible choices for high-value infrastructures and assets that are likely to be severely damaged during extreme weather events. Whereas, in some cases, continuous repair and maintenance work is often the best opportunistic adaptation effort and approach for dealing with smaller and more frequent weather events and for infrastructures that are less vulnerable to the changing climate. Overall, the selection of preferred adaptation pathways is one that is an iterative process with priority given to actions and options that can be immediately implemented or supported. Usually, these will be the ‘no-regret’ and ‘low-regret’ options and those that are robust across many futures [30].

(e) Developing possible timelines

This step entails the development of a sequence of potential actions into drafting adaptation pathways by drawing together all previous inputs to meet short and long-term adaptation needs under uncertainty. The tipping, turning and trigger points discussed earlier are utilised here to recognise when and under what conditions, a specific option may no longer work along with identifying when an action can or must be taken. Documentation of current activities is done first and decision points are identified to put in place ‘no-regret’ options and actions that shall be robust across most futures. This sequencing process can demonstrate any potential gaps between existing management practices and the resources, political and community support required to enable the adaptation pathway. One key thing to remember here for transport professionals is to ensure comparisons of current organisational conditions and adaption goals are being made for each and every scenario when developing the sequence of actions. This would allow to identify the key issues, risks and success factors that need prioritising and addressing [31, 32].

To develop sequences of potential actions, it is also important to analyse which actions are incompatible, from the technical (for instance, building a coastal dyke is incompatible with the restoration of coastal wetlands), financial or planning (some actions reduce the possibilities of adaptation on the long term) point of views [28].

Further, it is important that uncertainty regarding drivers of change guides the adaptation pathways development [33]. Uncertainty indicates that it is not useful to set predetermined and fixed implementation dates, instead it is much useful to set a decision criterion that shows when the circumstances are right for implementation [45]. Planning of adaptation pathways can enable actors such as transport professionals to get prepared for future risks and uncertainties by stipulating which measure(s) should be implemented now, and which should be planned for the future, to be implemented once a certain scenario or condition(s) is apparent. Also, the extent to which measures are flexible, reversible, 'low-regret', or robust (i.e., can perform reasonably under a range of future scenarios) must be considered by transport professionals [31, 45].

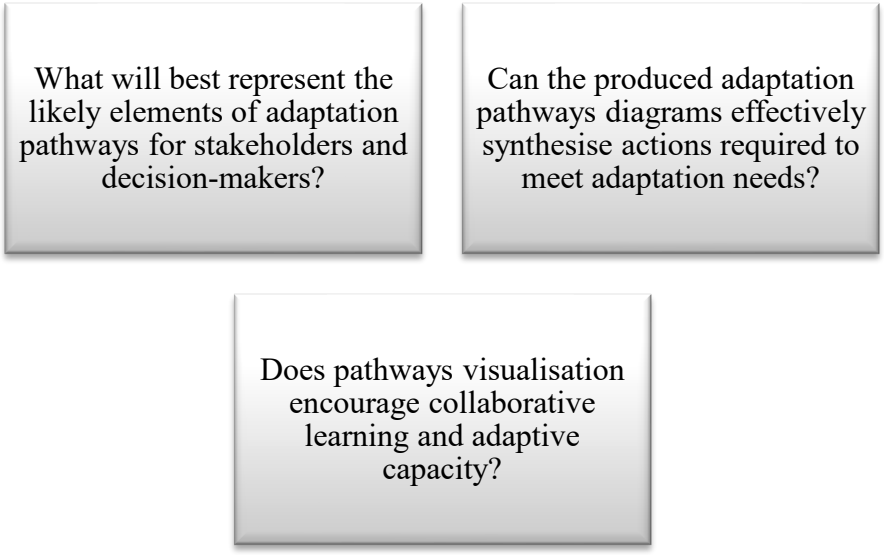
Guiding and learning questions for transport professionals in sequencing potential actions for drafting adaptation pathways.

How can measures be sequenced into pathways that meet short and long-term adaptation needs under uncertainty?	In the sequencing of activities and interventions, what role can the following play?: Lead-time, reversibility, flexibility, interdependencies, trade-offs, and robustness

(f) Finalising and visualising adaptation pathways

This is the final step in developing adaptation pathways and involves mapping out or visually documenting the sequence of potential actions. This visual representation of pathways can help with communicating outputs from the adaptation planning process [10] and assist with shared decision making to imagine a dynamic response to changing conditions, and to navigate the adaptation process [46, 47]. Currently, there are computer-aided tools and methods available that can assist transport professionals to portray potential adaptation pathways. Visual communication of such pathways can promote collective learning on the process of adaptation. Pathway diagrams can envisage the manner in which future adaptation needs are coupled with adaptation actions [48]. Also, the visual representation of policy decisions as a sequence of various smaller decisions over time can allow decision-makers to overcome some of the challenges linked with carrying out longer-term climate adaptation decisions [47, 49]. Once the possible adaptation pathways are defined, the decision-makers can then decide on their adaptation strategy based on the adaptation pathways, the level of risk to which their territory is exposed, their preferred adaptation strategy and their operational objectives [28].

Guiding and learning questions for transport professionals finalising and visualising adaptation pathways.



It must also be noted that incorporating multiple stakeholder engagements and their feedback, is not embedded in a specific step but relevant for each of the steps discussed above, in developing adaptation pathways. Certainly, engaging stakeholders that each have a set of values, goals, and knowledge base, across different levels and sectors can facilitate collective learning on the potential need for transformation. Stakeholders may provide differing goals, values and assumptions linked with the present and future, however their different attitudes, expectations and perceptions about the nature of climate change and how to achieve future goals along with their individual knowledges on guiding future possibilities may prove very useful for responding equitably to the changing climate, especially for sectors such as the transport sector [31, 47]. Undoubtedly, integrating the knowledge and expertise of multiple stakeholders has the potential to improve the quality of decisions made, mainly because of the comprehensiveness and inclusivity of diverse information inputs. For the transport sector, relevant stakeholders can play an active role in the identification of critical decision performance metrics, thus allowing to focus on the real issues faced by the transport departments. It is recommended that transport professionals interested in developing adaptation pathways for their transport infrastructure understand what type of stakeholder engagement would encourage collective learning about climate change, a common agenda for the future and an adaptive and transformational planning. Also, they must consider how stakeholder inclusion can support dealing with uncertainty and ambiguity in adaptation pathways [31]. As events become more frequent, the need to protect and transform becomes important, or even managed retreat. Here, stakeholder engagement is critical in informing and validating the adaptive responses, and to ensure that the needs of different groups are met.

(g) Implementing, monitoring and learning from developed adaptation pathways for transport professionals

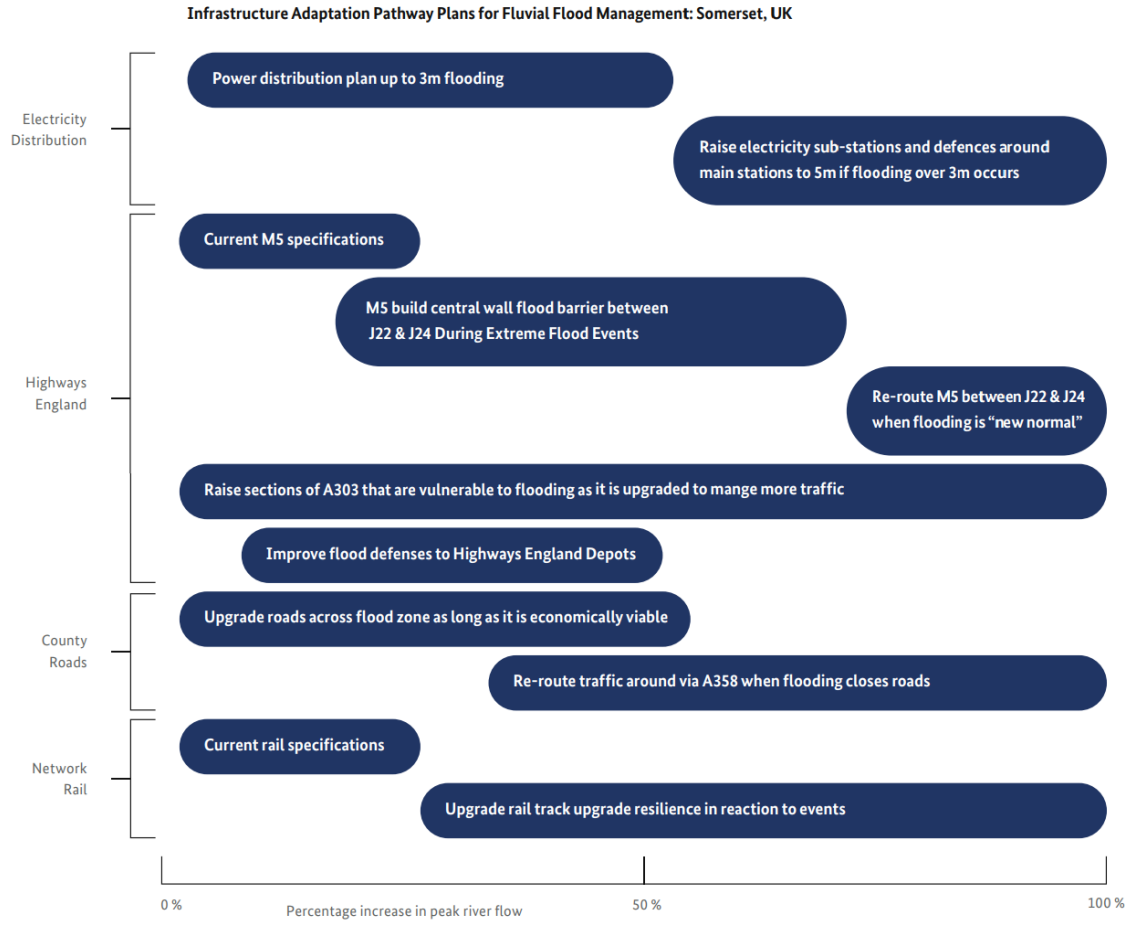
Any adaptation pathway map is aimed at reflecting the steps that have already been taken to increase climate change preparedness, identify decision points, consider alternative options and present possible timelines. Adaptation pathway maps should be shared, continuously revised, and updated as new information becomes available. As adaptation is dependent on learning and responding effectively to lessons learnt along with experience gained, changing circumstances, and new knowledge acquired, it is crucial that monitoring and evaluation is done regularly for ensuring an effective adaptation is carried out over time [49, 50].

Systematically monitoring implemented adaptation pathways can inform on-going decision-making and trigger follow-up activities that may be needed. This would allow for identifying when to re-evaluate the course of actions. Thus, the value of an adaptation pathway is proved when it is adopted, implemented and then updated over time within the sector.

It is evident that adaptation pathways are developed through the consideration of a sequence of actions based on the information that is available at present. It is expected that when applied over time, the pathway will meet challenges and possible barriers from the changing climate and its impacts, the social changes, economic and financial constraints and other crises. Taking into consideration the goals of sustainable transport, triggers to monitor will include extreme weather events, higher temperatures, more severe storms and flooding that can potentially affect the reliability and capacity of transportation systems while damaging transportation infrastructure. Transport infrastructure owners and managers should be keen observers of seasonal changes and monitoring systems. These professionals could work with local, regional and at times international agencies along with local communities, researchers, consultants and industries to share information and implement climate preparedness actions. Finally, transport professionals need to find a way to ensure that the adaptation pathways will be reviewed regularly as new information becomes available, as climatic conditions change and as adaptive capacity grows. For this, professionals also need to also recognise what processes are in place to increase the adaptive capacities of stakeholders. It is suggested that with constant review of the pathways, there may be a possibility of updating the pathways map in few years, if needed, as shown by the cyclic nature of the framework in Figure II. Thus, the proposed framework suggests that the development of adaptation pathways for transport infrastructures and assets should be a circular and iterative process that allows for new knowledge or socio-economic changes or changes to infrastructures as well as other modifications to be incorporated.

Figure III presents a recent example of an adaptation pathways plan for transport infrastructure resilience to different levels of flooding as part of the fluvial flood management in Somerset, UK [12]. Such an adaptation pathways map or framework allows decision-makers to have the flexibility to change the course of adaptation (i.e. switching pathway to implement suitable adaptation options) as new information becomes available [4]. The knowledge of the sequences of actions also allows to prepare for accommodating future adaptation actions in the designs of earlier actions. Through this, transitions between actions can be more effective and cost-efficient. The different phases in an adaptation pathways approach each contribute to a greater plan and are thus designed to allow for flexibility for future options, avoiding actions that may compromise effective actions in the future. Also, the effectiveness of the appropriate options can be monitored and evaluated with time and any learnings can be fed back into the next development cycle [3].

Figure III
Adaptation pathways plan for transport infrastructure resilience to different levels of flooding [12].



E. Case studies

This section will be developed after the 24th Session and is contingent on projects to apply the guidance framework.

F. Conclusions and anticipated benefits

This section will provide some concluding remarks based on the lessons learned from the case studies and is thus contingent on projects to apply the guidance framework.

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