10th International Conference on Through-life Engineering Service
16-17 November 2021, University of Twente, The Netherlands

Climate change in Dutch railway infrastructure: towards a framework for adaptation strategies

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Abstract

Extreme meteorological events such as floods, droughts, heatwaves, and storms cause significant damage to infrastructures across the world. These events can damage expensive infrastructural assets, but can also incur a high societal cost when disrupting the transportation of people, goods, and energy. Due to climate change, these extreme meteorological events will increase in severity and frequency in the coming decades. Infrastructural management organizations are, therefore, looking to adapt their infrastructural assets to cope with this. Existing literature stresses the need for translating climate risks and opportunities into concrete, mitigating actions. In practice, however, this translation poses a significant challenge for infrastructural management organizations. The challenges are further exacerbated by the high number of dependencies, and the need for alignment with both operational and strategic objectives and the interests of multiple internal and external stakeholders. To address this gap, a framework for identifying climate adaptation strategies and prioritizing the risks and actions is proposed. The framework can be used to identify, organize, and prioritize the 'missing links' between climate risk and adaptation strategies by taking into account synergies, prioritization, and an integral view. The novel features of the presented framework are explained by comparing it to practice at a Dutch railway infrastructural management organization. The evaluation of the preliminary framework suggests that it can assist railway infrastructural management organizations with developing concrete climate adaptation strategies in a smart way.

Keywords: Adaptation strategy; Climate adaptation; Climate change; Infrastructure management; Railway infrastructure;

1. Introduction

The global climate is changing and the frequency of extreme weather events is increasing [1]. These extreme meteorological events such as floods, droughts, heatwaves, and storms cause significant damage to infrastructures across the world. In the coming years, thousands of billions of euros will have to be invested in transport, energy, water, and telecommunication networks to preserve the connectivity, efficiency, and resilience of infrastructure [2]. Those infrastructures will have life expectancies of several decades and will therefore be exposed to the impacts of climate change [2]. Additionally, due to climate change an increase in the number and magnitude of the so-called NaTech events is expected (natural hazard triggered technological accidents involving the release of hazardous materials) [3].

Because of this, the need for Climate Change Adaptation (CCA), adapting assets to a changing climate, has attracted increasing attention both from practice and theory during the past decade. Quinn [1] mentions that it is highly desirable to consider adapting to extreme weather and future climatic change as part of effective asset management which contributes to business as usual, rather than regarding it as an optional or a separate stream of activity for which extra funding is required.

1.1. Climate change adaptation in the transportation sector

Because of the aforementioned challenges, the current transportation literature stresses the need for translating climate risks and opportunities into concrete, mitigating actions for CCA. Firstly Quinn [1] proposed an iterative framework that has the overarching ambition to embed CCA within organizational procedures. Secondly, Bollinger [4] proposed a framework for supporting governance for CCA of interconnected infrastructures. Thirdly, Moser [5] demonstrates a framework for diagnosing barriers to CCA. Fourthly, Preston [6] pays attention to CCA in practice, evaluating plans from three developed nations.

Among these infrastructures are railways all across the globe, where climate-related events are already among the factors frequently causing disturbances for railways [7]. In this context, Dépoues [2] discusses organizational uptake of scientific climate change information by infrastructure managers in the French railway company. Additionally, Lindgren [7] pays attention to CCA in practice: providing lessons learned on CCA of railways in Sweden.

Comparing the mentioned CCA literature revealed several important aspects and limitations for managing

Peer-review under responsibility of the Programme Chair of the 10th International Conference on Through-life Engineering Services.

CCA in infrastructures. Among these is the CCA process which includes prioritization, synergies, and consideration of CCA at multiple levels of analysis, which will be discussed in more detail further on.

1.1.1. CCA Process

The CCA process refers to the different steps leading to adaptation strategies. [1] mentions that the process should be responsive and iterative, and not linear. Furthermore, they also mention that people from different areas of a business or organization will have knowledge or experience which will be relevant for adapting to climate change. This personnel can lend support and expertise in the CCA process. In addition to this, [7] states that systematic mapping of types of climate threats, vulnerabilities, and consequences is necessary to guide the implementation of adaptation measures and prioritization of efforts. This systematic mapping is also highlighted in NaTech methodologies where attention is paid to among other identification of natural hazards, critical equipment, damage severity and probability [3].

Also related to the process, is the planning of CCA activities. [7] mentions that a weakness in the planning process of CCA is the lack of consideration of climate change impacts in the early stages of planning. Risk and vulnerability aspects are often dealt with in the later stages of planning, then the focus lays on the management of the risks rather than prevention.

1.1.2. CCA Context: Macro, Micro & Meso levels

The CCA context is concerned with variations in organizational levels, depicted in Figure 1. [1] says that through experience, organizations have found that there can be too great a step between overall organizational objectives that have potential national or international aspects (macro), and the individual adaptation actions that can be implemented in the short-term (micro), which ultimately can lead to stagnation of the adaptation process.

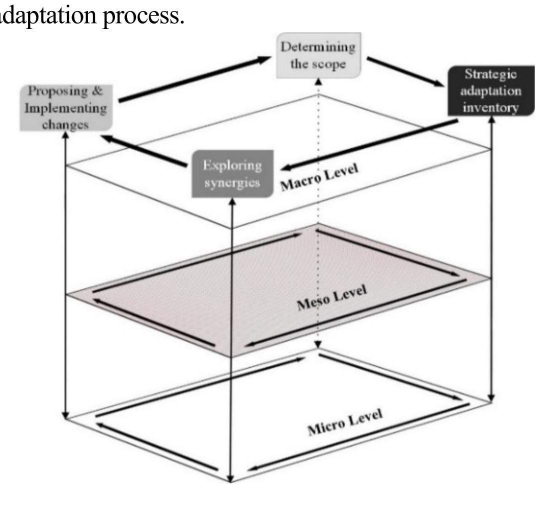

Figure 1: CCA context: Macro, Micro & Meso levels.

Furthermore, [7] says that based on lessons learned in the Swedish railway sector, no tailor-made climate change indicators were delivered (on a micro level). Additionally, according to several interviewees from [2], climate change will not just affect a few procedures or standards that could be easily listed, but will also have impacts across the whole railway system (macro level). All of this suggests the necessity of the intermediate meso level, linking the macro and micro levels.

1.1.3. Strategic adaptation inventory

There are never enough resources to carry out all CCA activities simultaneously, hence prioritization is required. Lindgren [7] says: to make well-founded prioritizations among different CCA measures, potential consequences of climate events should be thoroughly evaluated. Furthermore, appropriate methodologies should be used when performing risk and vulnerability assessments so that the results balance the frequency of events against their consequences in a systematic way. On strategic adaptation inventory, [1] mentions that considering hazards, vulnerabilities and losses enables a holistic approach that must determine the most significant risks to the organization and determines what risks should be addressed to achieve the objectives set out from the start. In extension, resilience assessment methods could help give insight in (less) vulnerable aspects/assets [8]–[10]. Their aim to assess asset resilience under individual or multiple hazards, at asset level, infrastructure network level, and community or national scale [10], could be complementary to strategic adaptation inventory, aiding the prioritization of critical assets.

1.1.4. Exploring Synergies

Synergy refers to the interaction or cooperation of two or more organizations, or other agents to produce a combined effect greater than the sum of their separate effects. [7] refers to synergies from a goal perspective: the possibility of creating synergies with climate mitigation goals and other environmental goals should be investigated and exploited. When planning and designing adaptation actions, the effects of potential goal conflicts should be carefully assessed, to avoid the implementation of counter-productive measures.

While existing framework and methodologies like e.g. NaTech methodologies pay attention to i.e. the risk identification and management, other important aspects like inclusion of synergetic opportunities are not taken into account.

The studied literature shows several important aspects and limitations for managing CCA in infrastructures, summarized in Table 1.

Table 1: Key aspects for managing CCA in infrastructures based on current transportation literature.

Process	The CCA process should be (1) responsive and iterative, and (2) should include expert knowledge. (3) Systematic mapping of climate threats, vulnerabilities, and consequences is essential to guide implementation and prioritization. (4) Considering climate change impacts in the early stages of planning results in a risk management focus, rather than a risk prevention focus.
Context	Concerns levels of CCA. The existing literature tends to focus on the micro-level (the impacts on individual infrastructure components) and the macro level. A void is left at the meso- or intermediate level.
Strategic adaptation inventory	A holistic approach is necessary to determine the most significant risks for organizations. Here potential consequences of climate events should be thoroughly evaluated using appropriate methodologies.
Synergies	Although mentioned from a goal perspective in CCA theory, a recognized gap is 'project' synergy, acknowledging that within a certain scope, multiple other projects/programs can be simultaneously present. Combining these efforts with CCA plans can result in multiple advantages (e.g. adequate usage of available resources like time, budget, manpower).
Integrality	CCA should be considered as part of effective asset management which contributes to business as usual rather than regarding it as an optional, or a separate stream of activity for which extra funding is required.

Furthermore, the existing literature indicates processes of 'what' needs to be done going toward CCA strategies, but not necessarily 'how' this should be done. In this regard, this research aims to develop a framework that consequently and effectively takes into account identified theoretical aspects and limitations for managing CCA from Table 1, focusing on the complex process of risk translation into concrete adaptive strategies.

2. Methodology

This research aims to address the aforementioned by proposing a framework for identifying climate adaptation strategies and prioritizing the risks and actions.

In order to do so, six in-depth semi-structured interviews were carried out within the Asset Management- and Corporate Control departments of the Dutch railway infrastructure managing organization. Based on the interviews, the current CCA process in the organization could be mapped, illustrated in Figure 2. Furthermore, these interviews confirmed the identified theoretical gaps in the CCA process mentioned in Section 1.2.

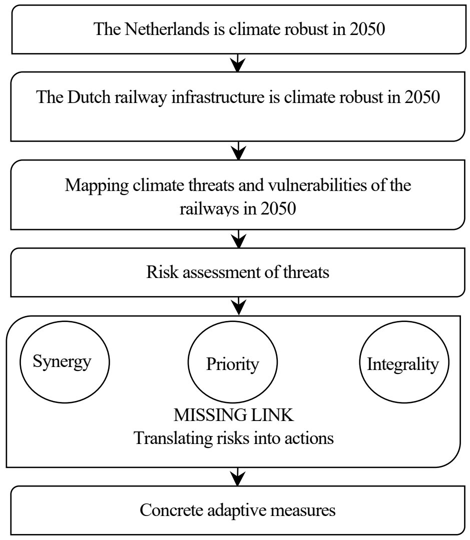

Figure 2: The CCA process at the Dutch railway infrastructure manager, including the identified 'missing link'.

These gaps are further referred to as the 'missing link' depicted in Figure 2. In this missing link, a few elements are identified as essential for the translation of risks into CCA strategies and actions. These elements correspond to some of the key aspects mentioned in Table 1: 'synergy' (synergies), 'priority' (prioritization) & 'integrality' (an integral view). The interviewees in the railway company have indicated difficulties with usage of the first two in the development of CCA strategies, and the relationship between them. The latter element, 'integrality' does not touch CCA solely, but describes the need for more integrality throughout the whole organization. It means that within an organization, where multiple projects run simultaneously, limited resources are better spent when various departments work together on shared objectives. When CCA becomes a part of that collaboration, it will fit seamlessly into existing policies and can become part of the business as usual, instead of a separate project that requires special funding.

With the use of these explorative preliminary interviews, the existing scientific literature, and archival research of organizational reports, essential design principles for the framework were determined. This led to important phases and key features included in the primary version of the developed framework. This version was afterward updated based on expert input from involved key stakeholders within the organization.

In the next sections, the preliminary developed framework is presented, followed by practical applications of the different framework features at the Dutch railway infrastructure manager.

3. The framework

The developed framework is depicted in Figure 1, and its detailed steps are shown in Figure 3. It consists of multiple facets:

- CCA Context: Macro, Meso & Micro levels

CCA plans need to fit both long-term strategic objectives as well as more immediate, operational requirements. Additionally, CCA involves collective action from multiple stakeholders at each level. A useful design principle was, therefore, to consider CCA at multiple distinct levels of analysis by adopting a macro-meso-micro structure [11].

- Step 1: Determining the scope

Depending on the level of abstraction, CCA strategies can range from a complete systems redesign to only a handful of simple improvement actions. An important first step is, therefore, to consider the goal and scope of CCA strategies, especially concerning the relevant climate effects, affected asset(s), geographical location, and the expected lifespan of the asset(s). The resulting system of interest (SoI) is input for the next phase, step 2.

- Step 2: Strategic adaptation inventory

The SoI can be investigated for scope-specific climate risks and subsequently prioritized according to the expected severity and/or frequency of extreme weather effects. Specific CCA strategies can then be generated which are tailored to a specific SoI.

- Step 3: Exploring synergies

In the next phase, these SoI-specific risk-based CCA strategies are compared and adapted to existing and proposed programs from both internal (company) and external stakeholders (e.g. municipality, utilities, and other railway organizations). By mapping and adapting CCA strategies to these existing plans, synergetic and/or collective efforts can be identified that may lower the burden of implementing CCA strategies and even solve multiple problems simultaneously. From these synergies and opportunities, a tailored strategy is formed, where it is possible that a risk that was supposed to be accepted, can be restricted due to a synergetic opportunity.

- Step 4: Proposing, evaluating & implementing changes

The tailored CCA strategy can then be considered for implementation by means of a cost-benefit analysis. Earlier phases may have revealed opportunities or limitations that require a reconsideration of the scope or the most appropriate adaptation strategy. The iterative nature of the CCA framework allows for multiple subsequent cycles of the four phases. It also allows for starting in either of the four phases, depending on whichever phase is most appropriate. This can lead to finding quick wins, even when managerial matters are not yet solved. These quick wins may not reach the desired quality, but waiting for the strategies to be implemented might lead to missed opportunities.

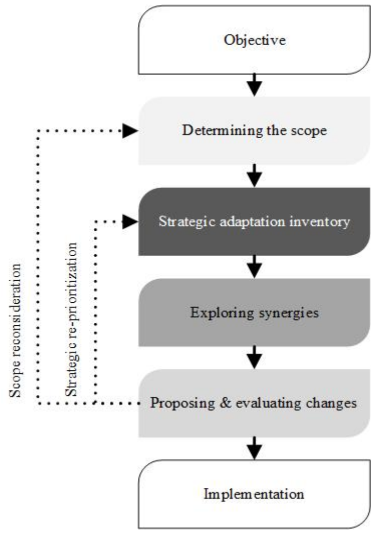

Figure 3: CCA framework: step-by-step.

4. CCA at Dutch railway infrastructure manager ProRail

4.1. ProRail

An example of a railway infrastructure manager is the Dutch organization ProRail. With one of the densest railway infrastructures of Europe, efficient and effective asset management is key. In addition to this, ProRail has identified climate change as a large (future) threat to its goals and ambitions. One of the main threats for the Dutch railway system is the increase in extreme rainfall, where tunnels and rails can be flooded and become inaccessible. Another threat is the expected increase in temperatures during summer, where electrical installations can overheat and fail. These expected effects of climate change can already be seen nowadays, where they disrupt service.

4.2. Framework application

In this section, the developed framework is explained by comparing its features to practice at ProRail. Moreover, this section explains how the different steps of the framework can be approached from a practical point of view. Currently, ProRail is exploring how CCA fits in its policies and programs and is developing multiple decision-making tools.

4.2.1. CCA context: Macro, Meso & Micro levels

The three different levels of context can be distinguished at ProRail, where the macro level indicates goals and ambitions at the organizational level and, the micro level contains the different projects that are carried out to manage and build the railway infrastructure. The meso level is essential for translation between these two levels and alignment between the different layers has to be achieved for consensus and cohesion. Examples from the meso level will be used for further demonstration of the framework, to emphasize the added value of this framework for organizations like ProRail.

An example of an input objective for the meso level is the ambition of the asset management department to make an asset climate robust in 2050. This objective can follow from strategies formulated at the macro level, or for instance from a reaction to an extreme weather event (at the micro level).

4.2.2. Step 1: Determining the scope

First, the scope needs to be determined. Here, ProRail has identified five climate effects, based on climate change scenarios from the Dutch weather institute, KNMI[1]. They recognize threats concerning heat, excess of water, drought, flooding, and storms.
For scoping on assets, ProRail looks at asset types or groups, or specific single assets that are significantly important and require their own CCA strategy. The same holds for locations, where critical sections of the railway network require specific attention. The lifespan of assets plays an important role as well, for example, the track bodies have an almost infinite lifespan, while rails and switches have shorter lifetimes and will endure less climate change in their lives. The SoI as output defines these four aspects in order to create specific strategies.

4.2.3. Step 2: Strategic adaptation inventory

ProRail has created maps where the vulnerabilities of the SoI regarding the different climate effects can be assessed. This shows for example the amount of flooding that is expected for a particular rainfall in a certain region. These threats can be translated into risks, by determining the impact and probability of occurrence, for which ProRail has developed its corporate risk matrix.

ProRail does not have the resources to eliminate all identified risks. Hence, risk prioritization, converging to risks requiring immediate attention, is necessary.

In order to do so, a lot of data has to be processed, including the knowledge and experiences from experts in the field. For this, ProRail is developing decision-making guidelines, together with the Ministry of Infrastructure and Water Management. They have defined four possible action perspectives: accept, repair, restrict and prevent, which need to be assigned to the risks, resulting in a risk-based CCA strategy. Following the guidelines using only the abstract data available, however, does not necessarily solve the decision-making problem. For this reason, it is proposed that expert sessions are organized in this phase, where experts from different backgrounds and management levels come together and discuss the inventoried data. Bringing these experts together gathers tacit knowledge present within the organization. Additionally, gathering experts from different levels of the organization creates alignment between these levels. That way, decisions can be made based on available knowledge and expertise, while aligning mentioned organizational levels.

4.2.4. Step 3: Exploring Synergies

An example of synergy in ProRail is the scheduled replacements of assets, such as electrical installations, which can be used to replace the asset with an updated and more climate-robust version. Acknowledging synergies can lead to (initially) unplanned CCA actions. A recent example of this is the railway station Driebergen-Zeist that has undergone a huge metamorphosis, where climate change was not included in the initial design[2]. During the adaptation process of this station, many stakeholders aligned on the desire to make the station climate-robust for the expected future increase in rainfall. This agreement resulted in specific CCA measures for the station and its surrounding environment.

4.2.5. Step 4: Proposing & evaluating changes

As shown in Figure 3, in some situations rescoping can be required after a cost-benefit analysis. An example of such rescoping in ProRail can be found in solving heat stress on railway stations. Here, it was primarily thought that the risk could be managed independently by the infrastructure managing organization. It became apparent, however, that cooperation with transport operators was required to solve mentioned issues, broadening the scope of analysis.

When no further re-scoping or prioritization is required, implementation of the CCA strategy can be done. An example of CCA implementation at the meso level is updating the design specifications of an asset, to ensure that all future built assets are climate-robust. This could mean: using different materials for electrical installations, or placing them on higher ground to prevent flooding. But the strategy could also lead to the

[1] https://knmiprojects.archiefweb.eu/?subsite=klimaatscenarios#archive. Accessed June 2021

[2] https://klimaatadaptatienederland.nl/actueel/actueel/interviews/toekomst-complex-spoornetwerk/. Accessed June 2021

design of a different maintenance- or replacement schedule. These strategies can then ensure that on the micro level, assets are built and maintained in a climate-robust way.

5. Framework evaluation

The practical examples of the proposed framework features provided by ProRail not just revealed 'what' can be done with CCA, but also shows 'how' an integral approach to CCA can be supported by four defined steps in the preliminary framework.

The preliminary evaluation of the framework suggests that it could assist railway infrastructural management organizations with developing concrete CCA strategies in a smart way by taking into account 'synergies', 'prioritization', and an 'integral view'.

The development of an 'integral view' can be supported by not thinking of CCA as a project on its own, but as something which needs to be included in the existing way of working where new assets are built and existing assets are maintained.

The consideration of 'synergies' appears to be a particularly welcome addition for ProRail, as it has the potential to integrate the resources required for implementing CCA strategies into already existing programs or to share these burdens with other stakeholders that have similar climate concerns. Combined with the prioritization step, this can considerably lower the barriers to take climate adaptation action, especially compared to actions that are initiated with only climate adaptation itself in mind. This process may lead to the identification of low-hanging fruit and no-regret actions. Therefore, an important question for future research will be how the framework can be most effectively applied, using the least amount of resources required.

6. Conclusions

Due to climate change, extreme meteorological events will increase in severity and frequency in the coming decades. This research proposes a framework that takes into account: prioritization, synergies, and integrality at different levels of abstraction. The framework aims to connect the strategic and operational level by considering CCA at multiple levels of analysis (micro, meso & micro).
Furthermore, the examples of practical applications of the framework features show how the different steps can be approached.

Finally, the evaluation of the preliminary framework suggests that it can assist railway infrastructural management organizations through the complex process of developing concrete climate adaptation strategies by determining a clear scope and focusing on systems of interest, exploring synergies, and based on this, having tailored adaptation strategies. After a thorough analysis, these strategies can be either committed to and implemented, or require rescoping and reprioritization.

Given the conceptual nature of this early design, further evaluation is required by testing the framework on a novel railway CCA issue from start to finish, going through all four steps. In a later stage, the generalizability of the framework can be further tested by applying it in non-railway contexts.

Acknowledgments

This research is co-financed from the Research and Innovation contribution (PPP) from the Dutch Ministry of Economic Affairs and Climate. The authors acknowledge the support of the NS and ProRail in the SIRA project.

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