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Climate Adaptation of Road Infrastructure – A comparison of the implementation of the CEDR ROADAPT and the FHWA Framework for Vulnerability Assessment in The Netherlands and Washington State

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Abstract

Since 2014, the United States Federal Highway Administration (FHWA) and Rijkswaterstaat in The Netherlands have worked together on the topic of infrastructure climate resilience. Currently they are implementing climate change or extreme weather resilience tools for infrastructure projects. They are both applying the ROADAPT framework (sponsored by CEDR) and the FHWA Climate Change Vulnerability Assessment Framework to projects in their respective countries: the SR167 completion project near Tacoma, Washington and the Innova58 highway expansion project in The Netherlands. This paper presents a discussion of the frameworks, the tools, the results of implementation, and shares perspectives the authors gained from using the tools to help future users understand the strengths and weaknesses of the tools. Both sets of tools have a similar approach and generally result in comparable outcomes. However, each tool has its specific qualities and applicability. The ideal tool is different for each situation. Both frameworks require expert knowledge to implement and interpret the results.

Key Words: climate change; resilience; vulnerability assessment; ROADAPT; FHWA Climate Adaptation Framework

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1. Introduction

The United States Federal Highway Administration (FHWA) and Rijkswaterstaat (executive part of the Ministry of Infrastructure and Water Management in The Netherlands) are working together on the topic of infrastructure climate resilience . Currently, they are testing implementation of climate change resilience tools developed in the United States and Europe on infrastructure projects in both countries. Experience with the tools will be used as guidance to improve the tools, to recommend tools best fit for specific circumstances, and to assist futures users with their application of the tools. Using the tools is anticipated to result in cost savings, as proactively planning for climate change is generally cheaper than waiting for infrastructure to be damaged. In addition, sharing knowledge from multiple parties generally reduces duplicative efforts and strengthens the final products.

As part of the project, US Department of Transportation Volpe Center and Deltares studied and compared the climate resilience frameworks:

- FHWA Climate Change and Extreme Weather Vulnerability Assessment Framework – a set of steps and techniques for assessing vulnerability and integrating climate change considerations into transportation decision-making.
- ROADAPT guidelines – a climate change adaptation framework for transportation developed by a consortium and sponsored by CEDR (Conference of European Directors of Roads).

Both frameworks contain methods and tools for conducting a vulnerability assessment. By assessing vulnerability one gains insight in locations on the road or road network that are susceptible to a certain threat and to what extent. Understanding vulnerability helps to improve the ability of the completed projects to maintain functionality under changing climate conditions.

The desk study was followed by the actual implementation of tools by the project team of WSDOT in the SR167 project and by the Rijkswaterstaat/Deltares project team in the InnovA58 project in the Netherlands.

This paper presents the main findings to date. The following sections provide a brief description of the frameworks and tools, a comparison of the frameworks and tools, a description of the infrastructure projects where the tools were tested, preliminary results on both sides, and a discussion of the users' experiences using the tools.

2. Description and comparison of Frameworks and tools

2.1 Brief description of the Frameworks

CEDR ROADAPT guidelines

The ROADAPT guidelines were developed by the ROADAPT consortium and sponsored by CEDR following the CEDR 2012 call 'Road owners adapting to climate change' (CEDR, 2015). The ROADAPT guidelines consist of a number of tools:

- Part A provides guidelines and tools for producing focused and consistent climate data and information with which to determine the impact of extreme weather and climate change on national and international motorways in Europe.
- Part B helps users quickly and efficiently determine the effects of climate change on infrastructure using an approach called "Quickscan". The Quickscan starts by filtering relevant threats from a comprehensive list. This list indicates the assets under threat.
- Part C offers tools for determining vulnerability to extreme weather and climate change using a GIS approach.
- Part D helps determine the socio-economic impact of the consequences of extreme weather and climate change on roads.
- Part E offers help in selecting adaptation strategies for limiting the impact of extreme weather and climate change.

FHWA Climate Change and Extreme Weather Vulnerability Assessment Framework

The Federal Highway Administration (FHWA) developed the Climate Change and Extreme Weather Vulnerability Assessment Framework (FHWA, 2012, 2015) through collaborative pilot projects with five state transportation departments and metropolitan regions in the United States. FHWA plans to release an updated version of the framework by January 2018, incorporating results from an additional round of 19 pilot projects that analysed transportation vulnerabilities and adaptation strategies.

The framework contains guidance on conducting vulnerability assessments and incorporating results into decision-making. It contains in-practice examples from the pilot projects, videos, and tools to assist in carrying out steps of the framework. The framework consists of three main segments: Define Scope; Assess Vulnerability; and Integrate Results into Decision-making. The Assess Vulnerability segment, which is compared with the ROADAPT Vulnerability Assessment tool in this paper, contains three tools (FHWA, 2015):

- The Sensitivity Matrix is an Excel spreadsheet tool that helps determine how (by which undesirable event) generic assets (roads, bridges, airfields, harbours, pipelines, and railways) may be negatively affected by 11 different extreme weather situations. The result is an overview of relevant undesirable events for each generic asset type with an explanation and in some cases a declaration of source. It can be compared with the Table of Threats in ROADAPT Guideline: Part B - performing a Quickscan on risk due to climate change.
- The CMIP Climate Data Processing Tool is a spreadsheet tool that processes the raw climate data from the World Climate Research Programme into relevant and usable statistics and projections for transportation planners in the United States, providing input for determining relevant threats from the climate.
- The Vulnerability Assessment Scoring (VAST) Tool is an Excel spreadsheet that guides the user through the implementation of a quantitative, indicator-based vulnerability analysis. In other words, vulnerability is determined based on various indicators or vulnerability factors.

2.2 Comparison of Frameworks and tools

The comparison in this paragraph is based on the desk study of the Frameworks by US DOT Volpe Center and Deltares and on the results of the implementation of tools in the SR167 and InnovA58 projects (projects are described in chapter 3). The users' experiences using the tools.is discussed in chapter 5.

The InnovA58 project team, which included staff from Rijkswaterstaat and Deltares applied the ROADAPT guidelines Part B - Quickscan method (Deltares, 2017) and Part C - Vulnerability Assessment (Deltares, 2017-2). Part A of the ROADAPT guidelines are less relevant for The Netherlands, as enough knowledge and experience in climate and climate forecasts was gained in past projects. Parts D and E (Socio-Economic Impact analysis and Adaptation Strategies) were evaluated less extensively for this project.

The InnovA58 project compared ROADAPT Part B and C with the FHWA Sensitivity Matrix and the FHWA VAST tool (Deltares, 2017-3). FHWA's CMIP Climate Data Processing tool is not relevant to the Dutch situation because it is only applicable for use in the United States, and KNMI (the Dutch Meteorological Office) provided the required information for the Netherlands.

The TRA 2018 paper 'Development of a Climate Adaptation Strategy for the InnovA58 highway in the Netherlands' (Leijstra et al., 2017) gives more detail on the project and elaborates on the test of the ROADAPT methodology – and Dynamic Adaptation Policy Pathways in the InnovA58 project.

WSDOT approached the comparison of tools somewhat differently than the InnovA58 project team. The SR 167 Project is a new project in the preliminary stages of design. Although a concept exists within a construction corridor, detailed engineering has not been completed. WSDOT had previously applied the FHWA Vulnerability Assessment Framework to complete a state-wide vulnerability assessment: Climate Impacts Vulnerability Assessment Report (FHWA, 2011). WSDOT compared the ROADAPT Part B: Quickscan and Part C: Vulnerability Assessment processes to the results of the prior qualitative vulnerability assessment, which included the highway segments that comprise the existing SR 167, I5, and other connecting highways.

WSDOT collected the spatial information to be used in the ROADAPT process for the SR 167 Project, but did not complete the detailed analysis since the alignment of the project has not been set. WSDOT also investigated the FHWA VAST tool.

Table 1 provides an overview of the applicability of and differences between the ROADAPT and FHWA frameworks, table 2 compares the ROADAPT Vulnerability Assessment tool and the FHWA VAST tool.

Table 1 also contains the definitions used for risk and vulnerability in both frameworks.

Table 1. General Comparison of the ROADAPT and FHWA Frameworks

	ROADAPT framework	FHWA Vulnerability Framework
Intended audience	National Road Authorities; broad range of professionals, including road engineers, asset managers, climate change adaptation professionals, innovation managers and project managers.	State departments of transportation (DOTs), metropolitan planning organizations (MPOs), and other agencies involved in planning, building, maintaining, or operating the transportation infrastructure.
Overall approach And definitions used	Adopts a risk-based approach using the RIMAROCC framework that includes 7 steps: Context analysis, risk identification, risk analysis, risk evaluation, risk mitigation, implementation of plans, monitoring. Risk is defined as a function of threat, vulnerability and consequences. Vulnerability is defined as a function of sensitivity, exposure and adaptive capacity. The vulnerability assessment does not emphasize adaptive capacity.	Focuses on vulnerability, which is defined as a function of: a transportation system's exposure, sensitivity, and adaptive capacity. A vulnerability assessment may also incorporate risk, which considers the severity or consequence of an impact with the probability that an asset will experience a particular impact. Exposure refers to whether the asset or system is located in an area experiencing direct impacts of climate change. Sensitivity refers to how the asset or system fares when exposed to an impact. Adaptive capacity refers to the system's ability to adjust to cope with existing climate variability or future climate impacts. The segment on incorporating vulnerability assessment into decision-making includes information and examples on incorporating into asset management, long range transportation planning, and project development and design.
ROADAPT Quickscan and FHWA Sensitivity Matrix	The ROADAPT Quickscan method helps determine the (generic) biggest risk threats in the area under consideration. As such it covers a number of steps i.e. determination of relevant weather related hazards, possibly resulting in a long list of threats (and types of threatened assets) and prioritization of the relevant threats. There is no specific sensitivity analysis. Which types of assets are sensitive follow from Table of Threats in the ROADAPT Quickscan appendix.	The framework includes a stakeholder based approach that is similar to the Quickscan but with less guidance. The information in the Sensitivity Matrix comes with a little more context and references to background information. For each asset type, it lists undesirable events that could take place because of a certain climate stressor.
Stakeholders involved in the process	Overall stakeholders are road owners and operators; recommends specific stakeholders not directly involved in road operation to participate in the Quickscan workshops. For the Vulnerability Assessment step, knowledge of GIS analysis and risk assessment is required.	Recommends a study team of transportation planners, GIS specialists, asset managers, state climatologists, climate change researchers, maintenance personnel, design engineers (e.g., structural, hydraulic, coastal) and natural resource agency personnel.

Table 2. Comparison of the ROADAPT Vulnerability Assessment tool and the FHWA VAST tool

	ROADAPT Vulnerability Assessment tool	FHWA Vast tool
Objective	To determine the most vulnerable locations for each undesirable event.	To determine the most vulnerable assets for one or more climate aspects (stressors) or undesirable events.
Factors	Factors are made semi-quantitative (0, +1, +2).	Factors are made semi-quantitative (0, 1, 2, 3, 4).

	ROADAPT Vulnerability Assessment tool	FHWA Vast tool
Format of results	GIS based; yields maps with continuous information.	Excel based; yields tables and graphs of assets in discrete locations (point information that is less suited to being put on a map).
Data needs	Requires spatial information in the form of maps or other information for each vulnerability factor and asset with enough detail; these need to be available.	Requires information regarding exposure, sensitivity and adaptive capacity of each asset that has to be analysed. This involves a lot of research, especially one wants to examine multiple locations. For example for use on the InnovA58 project, the route would need to be divided into hundreds of discrete locations/assets.
Weighting of indicators	In this method indicators are not given any weighting, it could be changed if required.	Indicators can be given a relative weighting factor if required.
Flexibility	Not easily amended (by people without GIS experience) if all information has been merged	Easy to amend and to 'play with' or manipulate indicators and weighting allowing for an indication of the sensitivity of the various factors.
Process guidance	No specific tool that accompanies the process; The guideline explains the steps that need to be taken.	The tool takes the user through the process step by step. For an inexperienced user it is not always clear what has to be entered where or how certain situations can be handled.
Steps	Clear steps showing how to come to a result.	The user has to click through various tabs without clear guidance to accomplish a result.
Examine Results	The results need to be examined using common sense while taking the quality of the input into account.	The results need to be examined using common sense while taking the quality of the input into account.

3. InnovA58 and SR167 Projects

The project teams tested both tools in projects in their respective countries: the SR167 completion project near Tacoma, Washington and the Innova58 highway expansion project in the southern part of The Netherlands.

The **InnovA58 project** as shown in figures 1a and 1b expands an existing highway in the southern part of the Netherlands from two lanes in each direction to three lanes in each direction. The project is not in a floodplain, as this part of A58 is above sea level. However, the project area experiences heavy downpours, which are increasing as the climate changes, resulting in localized flooding and need for enhanced stormwater management. The project is currently in the planning phase, and construction is expected to begin in 2020.

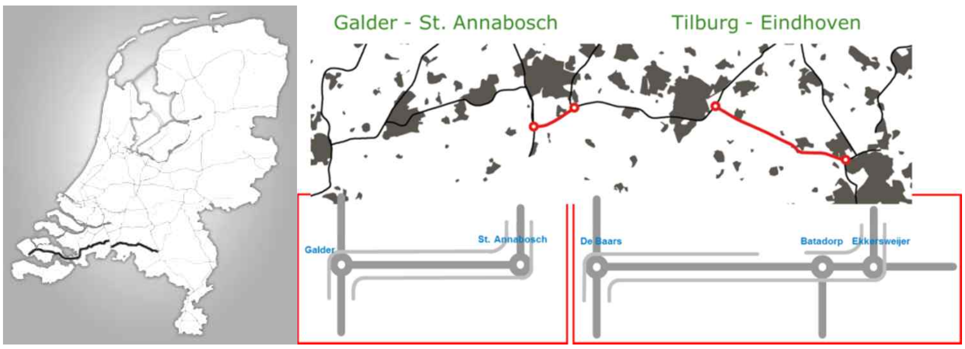

Fig. 1 (a) The A58 highway in the southern Netherlands; (b) The InnovA58 projected route is to be widened between the Galder and St. Annabosch interchanges and between the De Baars and Ekkersweijer interchanges. Between the St Annabosch and De Baars interchanges, major highway revitalization / maintenance activities is proposed.

The **SR167 Completion Project (SR 167 Project)** as shown in figure 2 will complete a critical missing link to Interstate 5 (I-5) near Tacoma, in Washington State. The project includes approximately 10 km of new construction and five new interchanges. The project traverses a floodplain of a minor tidal creek affected by sea level rise and is within the floodplain of a major river impacted by sea level rise, channel aggradation due to glacial retreat, and increased peak flows. The project area is experiencing increases in heavy downpours and continued urbanization that results in localized flooding. The project is currently in the design process. Environmental review, initially completed in 2007, is being updated to address design changes. WSDOT expects to begin construction in 2019.

Fig. 2 Map of the SR167 project near Tacoma, Washington.

WSDOT has developed a riparian restoration program (RRP) to convey stormwater through the project area as well to convey stormwater generated by the project. The RRP will create a sustainable natural corridor that reconnects the creek in the project area to the floodplain and adjacent wetlands, increasing conveyance and reducing flooding of the existing highway and local road network. As the RRP has substantially greater flow and storage capacity than a traditional closed conveyance and detention basin system, the RRP will provide resilience to any increase in local flows or runoff generated by the highway during the design life of the project. As the sea level gradually rises, the vegetation and channel morphology will continually adjust to the altering conditions.

4. Preliminary Results

4.1 InnovA58

The results of the implementation of the tools in the InnovA58 project are input for the current Plan Development Phase of the project.
The project team followed a Quickscan approach, as described in the A58 Quickscan report (Deltares, 2017). The Quickscan results detailed in the report indicate which undesirable events pose the greatest risk to the A58 and its surrounding area as a consequence of the weather now and in future, and which measures can be taken to counter them. The project team compared the table of threats in the Quickscan appendix with the FHWA Sensitivity Matrix. Both tools provide a total or comprehensive list of potential threats and associated hazards. These lists have a practically equal content, with minor differences. The Sensitivity Matrix provides more context and referrals to background information and thus possibly allows for the user to relate the results to their situation more easily. The table of threats in the ROADAPT Quickscan gives a more structured basis for the input needed in the subsequent Quickscan steps. The Quickscan then prioritizes the threats based on a generic threat comparison with no specific location information.

The FHWA Sensitivity Matrix does not compare the associated risk of the various threats. Prioritization of the threats using the FHWA methodology occurs in the VAST tool, which is location specific. Since the Sensitivity Matrix yields practically equal results as the table of threats in the ROADAPT Quickscan, it can serve to double check that all undesirable events for a particular project are identified. Applying the Sensitivity Matrix in the InnovA58 case did not yield any different data from the results of the ROADAPT Quickscan.

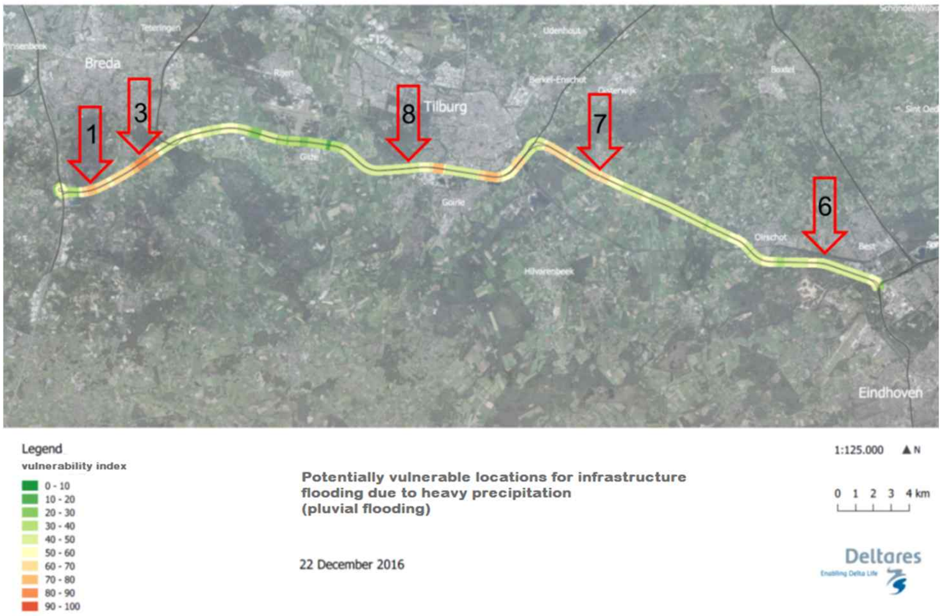

Fig. 3. ROADAPT VA results for Pluvial Flooding, indicating the vulnerability scores with colour codes.

For the ROADAPT Vulnerability Assessment process for the InnovA58 project (Deltares, 2017-2), vulnerability factor maps were created based on vulnerability factors and scores for each undesirable occurrence. As an example, the maps are shown for the events ‘Pluvial Flooding’ (figure 3) and ‘Insufficient Capacity’ of hydraulic structures (figure 4).

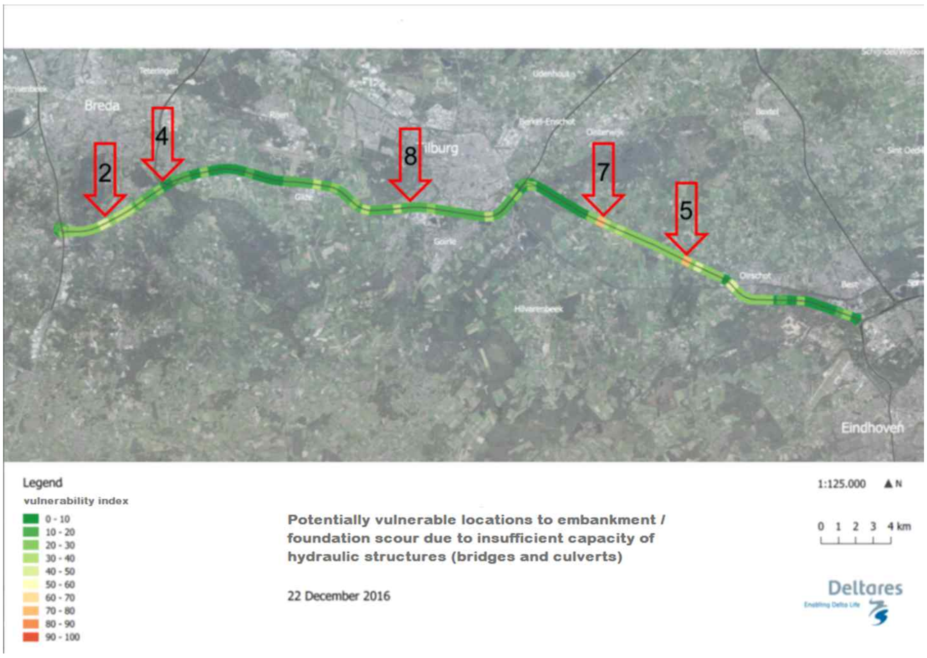

Fig 4. ROADAPT VA results for insufficient capacity of hydraulic structures along the A58. It shows where scour can take place as a result of insufficient capacity for water flowing underneath the highway

Following the application of the ROADAPT VA method, the project team used the VAST tool to draw up a list of priorities for ‘Pluvial Flooding’ and ‘Insufficient Capacity’ of hydraulic structures like culverts and bridges, using the same preconditions as for the ROADAPT method. The results were compared with the underlying maps in the ROADAPT VA analysis. The results for the InnovA58 project produced by each of the tools show strong similarities. Both identified similar locations and assets in the project area that are most vulnerable to the consequences of extreme weather. The results of both tools can be used to prioritize locations for adaptation strategies. This is described in more detail in the ROADAPT Vulnerability Assessment report (Deltares, 2017-2).

4.2 SR167 Project

WSDOT has not completed the full ROADAPT analysis, but rather compared the ROADAPT processes to those already completed by WSDOT in prior analyses. WSDOT found that the ROADAPT Quickscan generally followed the procedures used in the state-wide vulnerability assessment (FHWA, 2011) and identified similar broad concerns related to riverine flooding, high intensity precipitation and local flooding, and inundation due to sea level rise. These types of concerns are apparent to lay users, corridor planners, and engineering staff alike.

Using these general concerns in design requires an assortment of specialists to identify design concerns that that may not be apparent to transportation planners or environmental specialists. Without the specialized knowledge, the full depth of concerns may not be carried to the VAST tool. In contrast, the ROADAPT Vulnerability Assessment guideline (VA) provided a comprehensive list of potential concerns that can be used as a checklist. The ROADAPT VA helped identify secondary effects of sea level rise that could affect the SR 167 Project corridor (figure 5) and need to be considered in the design of the project: increased groundwater levels, saltwater intrusion, and increased tidal flux. WSDOT is currently investigating these additional issues.

The WSDOT vulnerability assessment process was not open to a large group of lay and specialists or a broad set of potential climate change impacts as suggested in the Quickscan process. The group consisted primarily of maintenance staff who were provided with a limited set of potential climate impacts. Segments of the highway that were already vulnerable to extreme weather events were identified and based on the limited climate change knowledge it was decided as a group if climate change would contribute to an increase the frequency, intensity or duration of the existing vulnerability. Consequently, the effects of climate change on design parameters that may be of interest to design specialists were not identified. For instance changes in groundwater level may be important to seismic safety design, saltwater intrusion may be important to concrete structure design including rebar selection, and changes in tidal flux may be important to sizing bridge openings to minimize scour.

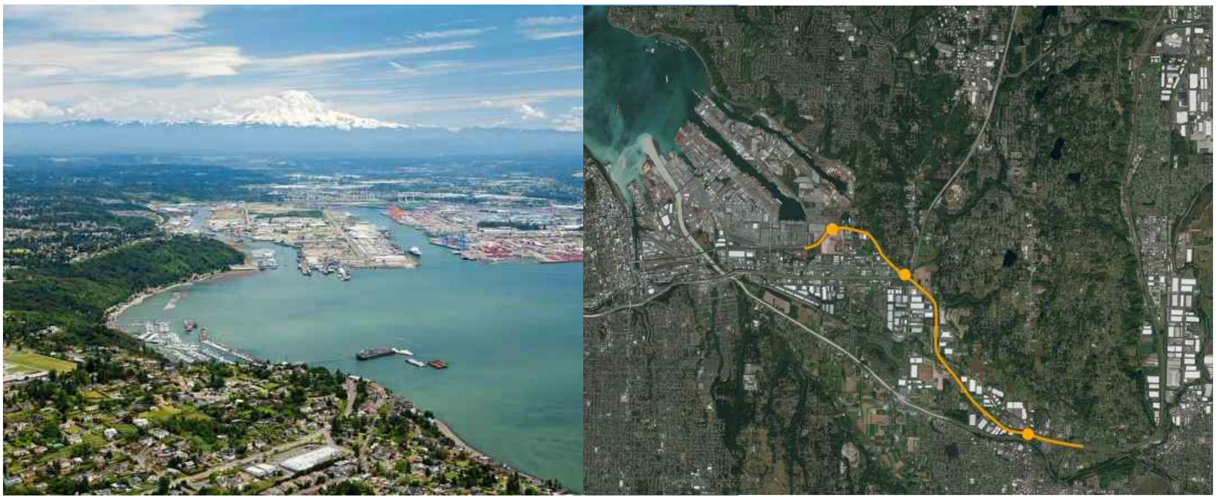

Fig. 5. (a) Aerial view of the SR167 project area, with Mt Rainier in the background and the Port of Tacoma in the foreground (b) SR167 extension projected on an aerial photo base map.

WSDOT also evaluated the consequences of vulnerabilities, considering factors such as traffic volumes, alternate routes, etc. to score the sensitivity of the highway segment to the identified vulnerabilities, which resulted in a high, medium, or low score that was further qualified with several levels of sea level rise. As with the ROADAPT framework, the scoring was simple for each factor considered.

WSDOT investigated the applicability of the FHWA VAST tool. The SR 167 Project does not have a detailed inventory of assets, so WSDOT referenced the State Highway Log (WSDOT, 2016) for the adjacent highway infrastructure. WSDOT found that the log is not georeferenced, and determined that adding extreme weather and climate change hazards to the log would not be practical for this project.
WSDOT also used the CMIP tool to evaluate changes in temperature and precipitation in the SR 167 Project

area. The output of the analysis provides only daily data. This data may be useful in designing detention facilities, but is of little value for conveyance design.
Data or relationships that relate potential changes in daily maximum precipitation rates to high intensity short duration events have not been developed in Washington State. These short duration events are likely to impact driving due to aquaplaning or lane closures due to spread of shallow water into the traffic lanes.

5. Discussion

The following discussion is the result of the study of the frameworks and tools by both the US Department of Transportation Volpe Center and Deltares, and of the actual implementation by the project team of WSDOT in the SR167 project and by the Rijkswaterstaat/Deltares project team in the InnovA58 project in the Netherlands (Deltares, 2017-3). The comparison of the frameworks and tools is summarized in the tables in chapter 2.

Both the ROADAPT table of threats in the ROADAPT Quickscan process and the FHWA Sensitivity Matrix can be used to identify assets sensitive to extreme weather, and can be used interchangeably. Whichever methodology is selected, the user should check whether the results are complete and are representative of their own situation based on personal knowledge of the infrastructure and extreme weather in the area.
The FHWA Sensitivity Matrix can easily be applied and provides a fairly complete first indication of the relevant undesirable events. It may be most useful to road managers with less experience in and knowledge of the sensitivity to extreme weather and climate change of the assets in their network, and as a result are unable to identify undesirable events themselves. In addition, the Sensitivity Matrix can help determine vulnerability and other indicators that can be used in the FHWA Vulnerability Assessment Scoring (VAST) tool.

Deltares (2017-3) concluded that the FHWA VAST tool, as compared to the ROADAPT Vulnerability Assessment approach, allows more manipulating of factors and weighting and thus gives an idea of the sensitivity/robustness of the results. Applying the VAST tool may be favourable if the user already knows which locations need to be focused on and wants to determine the vulnerability of these locations. In addition, the VAST tool can be used when one wants to check how changes in various indicators affect total vulnerability. Unless data already exists in an asset management database that can be readily transferred, it is not practical to enter more than a few dozen locations in VAST. No specialized knowledge is required to use the VAST tool, although it requires a lot of (detailed) inputs that may require specialized knowledge to obtain. From a practical point of view, the VAST tool may be improved by making a more user friendly input method that guides the user through the process.

The differences in outcome of the vulnerability assessment between the tools in the Rijkswaterstaat InnovA58 project are small, and the project team had no preference for one of the methods over the other.
WSDOT found that both sets of tools could be used to identify and rank vulnerabilities to extreme weather and climate change. Based on spatial data, the ROADAPT framework lends itself to sharing the information to the public and other lay users. The FHWA tools are largely spreadsheet based and consequently the data is less accessible to a wide audience.

Concerning practical experience using the ROADAPT Quickscan method, the Rijkswaterstaat and Deltares project team found that it is challenging to get the required road asset managers together in a workshop setting, let alone for multiple days of workshops. As a result, not all the scoring and subsequent discussion could be concluded in one session and with the same people, resulting in inefficiency. Note that this is not specific to the ROADAPT methodology but is something that should be taken into account when choosing to execute such an analysis. Similarly, Rijkswaterstaat and Deltares found that some information, e.g. level of maintenance, is difficult to find, especially in a GIS format that can be used for the ROADAPT Vulnerability Assessment.
The ROADAPT Vulnerability Assessment (VA) approach requires GIS skills and data available in a usable form with the right level of detail. This data is often publicly available, but can prove problematic to find. The ROADAPT VA tool may be improved by adding variable weighting to the vulnerability factors and adding factors for adaptive capacity. This would allow users to easily manipulate the various vulnerability factors without having to change underlying data coding in the GIS environment.

WSDOT found that their highway inventory data was not directly usable in the FHWA VAST tool and that significant efforts would be needed to add the hazard information needed to properly use the tool. WSDOT is using GIS and other georeferenced tools for current designs; however, projects more than approximately 15 years old only have electronic CAD files or paper copies.

6. Conclusion

The project teams in The Netherlands and Washington State found that the ROADAPT and the FHWA Climate Change and Extreme Weather Vulnerability Assessment Frameworks are excellent frameworks that can be used and customized by other users to effectively identify extreme weather and climate change vulnerabilities, prioritize those vulnerabilities, and develop adaption strategies. The tools that are part of the frameworks each have their specific qualities and applicability. The ideal tool is different for each situation. It was noted that the results of the methods are indicative and a final check based on expert judgment is of great importance.
The main benefit of using tools to assess vulnerability is that the tools help the user determine the most vulnerable locations in a most objective manner. This takes away any personal bias or over representation of well-known locations or assets.

Also the project teams found great value in testing the frameworks and tools in different countries and contexts. FHWA is using the knowledge gained from testing both sets of tools in the update of the FHWA Framework. Rijkswaterstaat uses the knowledge and experience for improved implementation of the ROADAPT framework, for the benefit of other projects in the Netherlands. The comparison can help future users understand the strengths and weaknesses of the frameworks and the tools to be able to best apply them in their own projects.

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