CReDo

Conceptually expanding and testing future expert elicitation methodologies and its outputs in CReDo

Table of contents

Authors

Author: Stephane Fernandez Garcia (Connected Places Catapult),

Contributors: Dr. Kevin Wilson (University of Newcastle) and Prof. James Smith (University of Warwick)

Introduction

CReDo is a climate change adaptation digital twin that brings together data from the energy (UK Power Networks), water (Anglian Water) and telecommunications (BT Group) sectors with flood data with the aim to understand infrastructure interdependencies, asset and system climate derived failure impacts. The project is currently being developed with a strategic planning and investment use case at its core, whereby providing cross-sector insights to asset owners, better decision making in investment resilience can be made, maximising the impact of these.

In order to generate relevant insights to support this use case, CReDo needs to resolve what the impact will be on individual assets. That said, the highly interdependent nature of these infrastructure networks, such as key water supply assets relying on power supply assets to be operational, mean that to reliably model the impact of weather events, CReDo also needs to resolve how individual asset failures will cascade and impact other assets that are connected to them (both in their own and other infrastructure networks) This ability to obtain cross-sector insights is CReDo's main pathway to creating value and impact in the UK infrastructure landscape.

This report focuses on one component of the CReDo modelling and insight generation processes, the individual asset modelling. The work done in phase 1 (please refer to the CReDo technical report 3: assessing asset failure available in the DT Hub for more detail) demonstrated how it is possible to elicit from asset owners the probabilities that each of their assets might fail in a particular future flood scenario. It also demonstrated how to use the outputs of the expert elicitation methodology to build Bayesian Network models that could potentially be implemented in CReDo. This report outlines the follow-up foundational work that was completed during the second phase of the project (in the 2022/23 financial year); this work should be taken as a further piece of development for the concepts introduced during the first phase. To fully understand this report and its implications, it is advised to read the phase 1 report that was introduced above.

Scope

This report is only intended to provide a high-level view of the additional development work done during CReDo Phase 2; this was focused on investigating how to overcome some of the drawbacks of the expert elicitation method that was tested in the first phase of the project. This document will:

- provide a high-level description of the modified methodology used for expert elicitation sessions in phase 2.
- list the lessons learnt obtained by running new expert elicitation sessions using a modified methodology.
- outline the outputs and data obtained by using the modified methodology.
- provide a general view of the next steps needed to further develop this area of CReDo.

This report will not provide detailed information regarding the outputs of the elicitation sessions as these are considered to contain sensitive information. The overall elicitation and modelling methodology is still in development and it is expected to change in future phases of the project.

Development of the methodology in CReDo phase 2

As introduced in earlier sections of this report, the work done in phase 1 successfully tested that it is possible to obtain asset models by eliciting probabilities from subject matter experts (SME) in asset owner organisations. Typically, the process involves both a structural and a probability elicitation session; the first is focused on understanding what are the key drivers and variables that describe an asset behaviour in your context of interest (e.g. a flood event) The second session aims to elicit probabilities for specific events related to the drivers/variables of interest. Using information from both sessions it is possible to build a Bayesian Network (i.e. Bayes Net model) This methodology is flexible and can be used to represent highly complex systems and assets for a variety of extreme weather events. However, there are also a number of practical scalability challenges that were identified.

- To obtain statistically valid and representative results, the expert elicitation sessions need to be framed around a specific asset and weather event. This means that the models obtained with the outputs are, in principle, only applicable in that specific context (i.e. the asset and event in question) This means that to obtain models for the whole asset base, the CReDo team would need to run one elicitation session for each possible pair of assets represented in CReDo and weather event. This would result in a high number of in-person sessions that would not be practicable to complete. As such, the project has set the foundations of an aggregation and generalisation methodology that could be used to overcome this scalability issue. This is focused on how to aggregate the outputs of a very reduced number of elicitation sessions and how those can be generalised to attach custom models to each individual asset.
- The phase 1 methodology also requires highly specialised individuals (e.g. mathematicians) to prepare, organise and deliver long in-person workshop sessions with SMEs to elicit information and probabilities. This represents a practical problem as asset owners are dependent on third party expertise and eliciting information is time consuming and often not compatible with or flexible enough to account for asset specialists' workloads. Generally, this does not align with the increased lean and agile approaches to innovation/process development, implementation and limited budgets that industry is currently using or is limited by. To overcome this challenge, the CReDo Team conceptualised that the use of a digital elicitation tool that embeds and democratises some of the most complex aspects of the elicitation process could empower SMEs to be able to lead on the elicitation and streamline the process. This concept was further developed as part of an Ofgem regulator funded project via the Strategic Innovation Fund (SIF); for more details please refer to the Energy Networks Association project page where it is possible to download key specific documents providing an overview of the current status of this development. Alternatively, there is a "show and tell" session that was delivered as part of the project that is publicly available in YouTube.

The methodology followed in phase 2 was tailored from the more traditional approach used in phase 1; the aim is that the modified methodology would function as an early test of an elicitation setup where asset owners would face aspects of the process more independently. This provided valuable learnings for the process as a whole and, particularly, for the design of a digital elicitation tool.

Expert elicitation methodology used in Phase 2

This subsection outlines the methodology that was used for the purposes of expert elicitation in the second phase of CReDo. Key characteristics of this iteration of the methodology are outlined below:

- This is a modification of the Phase 1 methodology that was heavily reliant on involvement of facilitators and experts for structural and probability elicitation; both types of elicitations were organised as group engagement sessions.
- Phase 2 methodology is aimed at testing some of the key aspects of a future technology-driven solution for expert elicitation sessions that is less conditional on having face-to-face interactions between facilitators and experts.
- Structural and probability elicitation sessions were delivered for 10 different types of assets; these are listed in table 1 below.

Table 1. Assets considered for elicitation in phase 2 of the CReDo project.

Asset number	Infrastructure network	Asset name/description
1	Energy (Distribution Network Operator)	Primary substation
2		Secondary substation
3	Water	Sewage pumping station
4		Water pumping station
5		Water recycling centre
6		Water treatment centre
7		Ground water source
8	Telecommunications	Tier 1 exchange (MSAN)
9		Cabinet
10		Mobile mast site

Structural elicitation

This first part of the elicitation process focuses on obtaining information that allows to identify the key drivers and variables that determine asset behaviour in a given context (e.g. a flood event). Key aspects of the methodology used include:

- Informal structural elicitation sessions were run. The structures were determined based on:
    - Phase 1 expert elicitation learnings.
    - Frontier Economics data on resilience strategy and defence from Asset Owners obtained as part of workshops aimed at developing economic modelling in CReDo (for more detail, please refer to CReDo Phase 2: Developing decision-support use cases - Public Resources - DT Hub Community (digitaltwinhub.co.uk)
- The structures were validated with key contacts from asset owners in 1-hour calls. The aim was to ensure that the Bayes Net structures were representative of how assets work/fail. The project team aimed to find a balance between simplicity and avoiding missing major drivers of asset failure.
- The validation process was based on showing simplified structures to contacts in the asset owner organisations and asking key targeted questions to clarify the role of and how resilience measures are used in the context of a flood event.

Probability elicitation methodology

This part of the elicitation process focuses on asking very specific questions that aim to obtain probabilities that can be attached to each of the key elements defined in the structural elicitations.

One of the key objectives in the second phase of the project was to reduce as much as possible the need for face-to-face interaction with experts and, also, to target sessions with individuals instead of groups. This is to partially mimic an environment where SMEs would not have the support of highly specialist staff (i.e. similar to the environment that the digital elicitation tool mentioned in previous parts of this report is trying to create as part of its user experience)

General aspects

The key aspects of the probability elicitation methodology used in phase 2 are outlined in the following bullet points.

- The sessions were targeting individuals as opposed to groups of SMEs.
- The duration was set at 30 minutes for the elicitation of 1 asset. An additional 15 minutes per extra asset was added when eliciting probabilities for more than one site.
- It was important to prepare experts before the sessions. Pre-read packs were shared with the individuals containing:
    - general aspects and context of the methodology.
    - a description of the specific asset and climate scenario to be used in the elicitation session.
    - the questions that were going to be presented as part of the elicitation.

    These were designed to provide experts the knowledge they needed to answer the questions successfully and independently and maximise the time spent in answering the questions.

- The probability elicitation questions were checked with key experts in asset owner organisations beforehand to ensure they were clear and relevant, but not with all participants. This was done over e-mail communications.
- Expert elicitation sessions can be focused on more than one asset when a single expert is capable of providing insight into the failure mechanisms of more than one type of asset.
- The session included feedback questions at the end to encourage experts to share their views on how the process can be improved.

Description of specific elements in the elicitation session

1. **Introduction to session and training** (online session – time allocated: 10 mins)
    - Included introducing individuals to underlying aspects of the session and methodology (*e.g.,* subjective nature, anonymity)
    - A training exercise was also completed aimed at helping experts understand how they are expected to approach questions, encourage the use of previous experience and sharing of rationales, and the use of simple probabilistic comparisons to help with selecting specific numbers.
2. **Introduction to scenario** (online session – time allocated: 5 mins)
    - This part of the call was focused on providing a description of the specific scenario for which individuals were expected to provide probabilities.
    - Similarly to the methodology in phase 1, it is necessary to define one weather scenario per asset type.
        - The key is to find an intermediate point that is not too extreme, but at the same time, extreme enough. The aim is that individuals have to think and make use of their expertise to provide a probability, *i.e.,* avoid situations where probabilities are obvious (i.e. easily given as “0” or “1”)
        - Also, it was important design the session to avoid individuals from “averaging scenarios” in their mind. The probability should be related to the one-off scenario described and linked to unique and unambiguous events and questions.
3. **Elicitation of individual’s probabilities** (online session – time allocated: up to the end of the call)
    - Microsoft Forms was used for presenting questions and as a mean to capture the information.
        - The expected outputs were a number (i.e. probability) and a short justification for said number.
    - The facilitator was still present during this stage to provide guidance and general support if experts had any problem accessing MS Forms or understanding the questions.
    - It is key that the questions were clear to ensure that they were being understood and interpreted in the intended way. Otherwise, there is a risk of probabilities being provided for the wrong event (i.e. an event different to the one that the organiser is expecting to obtain answers for)

Further steps after elicitation

As mentioned in previous sections of this report, it is desirable to generalise the probability elicitation outputs to a wider set of assets in CReDo. This is key to ensure this type of methodology is practicable on a CReDo scale since it is not feasible to elicit probabilities for all combinations of assets and climate scenarios.

Outcomes of elicitation could be used to build a model that is more widely applicable (*i.e.,* to other scenarios and/or asset types). Despite being based on specific scenarios, the information obtained from the elicitation could be used for this purpose when sessions are designed accordingly. This could lead to, for example, a regression model (*e.g.,* for each asset type or a more generic one). The inputs would be the information regarding climate scenarios etc. (*i.e.* defined as part of the probability elicitation sessions); the output would be the probability. This, in principle, could be generalised to a CReDo scale where the inputs, in a deployed model, would come from the system itself upon user selection. The above description is just intending to provide an example of how specific outputs could be generalised, other approaches are and will also be developed as part of current and future project efforts. To learn more about the ongoing work in this area, please do reach out to the CReDo Team.

Outputs and lessons learnt

Outputs

The outputs of the elicitation sessions include:

1. **A probabilistic structure** that contains the elements that are key in determining how an asset behaves in a given context. Relationships between the different elements are also captured as part of the structure. In simple terms (i.e. these should not be taken as technical formal definitions), a probabilistic structure contains the following types of elements:
    - **Initiators**: represent the main root cause of a potential threat to an asset. For example, a storm that is, then, likely to cause a flood.
    - **Physical threats**: are elements that represent the actual threats to the asset, for example the flood. In the case of flood, there is an inherent severity attached to it in the form of flood depth.
    - **Asset components**: components or operational aspects of an asset that play a critical role in determining the asset behaviour (e.g. electrical components of an asset)
    - **Failure mechanisms**: the physical mechanism that ultimately can cause an asset to fail (e.g. asset electronic wetness)
    - **Mitigation elements**: intended to represent measures that provide containment (i.e. help avoid the consequence of the physical threat) or mitigation (i.e. delay the operational impact of the failure). For example, this could include the presence of a concrete boundary with flood gates and/or power back-up generators.
    - **Others**: any other elements that do not fit within mitigation elements or asset components, but play a key role in describing the behaviour of the asset.
2. **Probabilities** that can be attached to the elements in the probabilistic structure.

Lessons learnt

This subsection outlines the key learnings discovered or refined during the second phase of the project. These have been structured in two sub-sections that mirror the stages of the expert elicitation approach (i.e. structural and probability elicitation) The first section discusses the elicitation of a dependency and interface structure between elements that is then moulded into a Bayesian Network structure as the key output of the structural elicitation stage. Then, the following section 'Probability Elicitation' discusses the lessons and learnings from eliciting probabilities that are to be assigned to the Bayes Net.

Structural Elicitation

1. Members of staff that are "office-based" in more strategic type roles don not always have all the critical information needed to build the models. **People in charge of the day-to day operations of assets provided additional highly useful information.** Some recommendations of groups to target to obtain an adequate view of the relevant processes can be found below:
    a. **Strategic Operations** response staff have a good overview of the general response protocols in the company and any limitations around their application.
    b. **Crisis Management** staff will have information on how the business finds a balanced response to certain types of emergencies and what are the most likely measures to be implemented to deal with these situations. They will also know about how applicable some responses are and what might be the limitations (*e.g.,* number of back-up generators available, budget constraints etc.)
    c. **Engineers** (preferably the person responsible for the specific site/s that are being targeted as part of the elicitation) have detailed expert knowledge of the sites' (typical) layouts and configurations and how likely containment or preventative measures are to work in emergency situations. They also have expert knowledge of how robust, resilient, maintained etc. the equipment installed on the sites are.
2. The **"what can happen and why"** to certain assets, when threatened by the environment is critically important to understand. These enables to frame the topology of the underlying Bayes Net.
3. **Talking through how things could happen slowly was really helpful**. Getting stakeholders to relive particular incidents and explain what and how things happened then and what might have happened was extremely helpful. Most of the expert information critical to the problem at hand was embedded in such stories**. Past events are a key an efficient way of obtaining such information.**
    a. In general, the experts' own memory of the events should be sufficient. It is important to remember that the methodology is based on their own, subjective experience. As part of this, it is advisable to avoid pieces of information that could bias their own understanding of the situation, perhaps if there are robust data that was captured internally as part of the response to those past events, it could be used as an un-blocker for the discussion or to obtain further insights once they have been given the chance to provide their views.
4. A lot of the **critical information was buried to the non-specialist**. For example, the single major effect of flooding was the exposure of electronic equipment to water which would then cause a fire and burn out the equipment. So, exposure of electronics to water is key to whether or not an asset failed. If something did fail, then those electronics would typically need replacing which would need engineers to do this once the station had dried sufficiently. Another example of this type of situation was the existence of back-up power and whether these would work and for how long and whether these sources of power were themselves subject to exposure because of the flood.

5. The **meaning of terms may be ambiguous**. For example, for CReDo an asset failure would mean that it is not working. That said, a pump might not technically fail – in the sense that the motor is still running, but still fail in the sense of being ineffective. Eliciting this sort of information can be critical.

    a. It is important to tailor the elicitation to what CReDo can then model and output. As the technology evolves, elicitations (and their corresponding derived models) can be updated to account for new functionality. It is key that the questions and information in which the elicitation is reliant are completely unambiguous; for example, what is understood as an asset failure should be clearly defined, so that experts can provide insights in accordance with that.

6. When investigating past events it can provide useful insight to ask **why it look so long to fix a fault and why events leading to a failure happened**. For the Bayes Net this can encourage to add new elements in the Bayes Net. For example, one of the insights in the sessions was that in a flooding incident typically a crisis centre would be set up – sometime before the event and restrict engineer access. So, acknowledging that engineers may not be able to access assets to add protective measures or do remedial acts may not be possible was important. Also, that they may not even have the vehicles or human resources to do this.

7. Time of day of the flood had a big impact because of resource and demographic issues.

    a. Resources (both human and material) might not be as readily available depending on the time of the day and the potential restrictions on short, medium and long-distance travel options (*e.g.* trains not running at certain times at night etc.) It could also have budgetary impact on having to pay a large number of staff members “out-of-hours” wages etc.

8. There is always a dissonance between what data is available and what measures might inform the system where they are available. The advice is to, in the first instance, **build Bayes Nets which assume that you could get perfect information on everything useful**. Only after this, acknowledge that for various measures you may have no information on.

    a. Mapping the events and action-reaction chains in the operational process is a good starting point. Operational manuals, decision trees and similar documentation can help establish a good starting point for building a Bayes Net structure. These can then be used to build a basic first version of a structure by thinking of the specific triggers and relationships between key elements. Finally, testing your understanding of these by questioning experts to refine the overall structure is important.

    b. It is not particularly advisable to show any full Bayes Net structure to stakeholders as they might not interpret it correctly, but perhaps snapshots or specific questions based on it can be shared to validate the structure.

    c. Bayes Nets can be very complex, it is critical to set a realistic target. The Bayes Net that is taken forward to probability elicitation and modelling should be seen as representative of reality to an agreed acceptable degree. The recommendation would be to remove elements that are not likely to be significant in representing reality to a good enough level. Also, consider if there are some elements that can be solved via other methods that are not necessarily linked to an elicited probability (e.g. physical-chemical models)

Probability Elicitation

Key learnings in this area include:

1. Support is critical – probabilities changed as questions were clarified, so having support available is important when running elicitations.
2. It is important to focus on a specific asset in a specific event otherwise the experts will not be able to provide probabilities.
    a. It is important to write questions in a unique and unambiguous way that avoid experts from averaging numbers in their minds, specificity is key.
3. It is advisable to interact with different types of experts, particularly experts who are directly responsible for a specific asset as there are local issues that other experts will not be aware of.
    a. As an example, previous sessions linked to CReDo had a lead engineer who worked on-site at the asset, an emergency planning manager, an asset performance specialist and a regional flood risk manager.
4. The experts need to be prepared for the elicitation in advance. This requires the production of a comprehensive (but not extensive) briefing document.
    a. These contain general information of the context and method of elicitation, a description of the climate scenario & asset and the list of questions to be asked.
    b. Additionally, any quantitative evidence on any of the quantities which are the subject of the elicitation should be included in the briefing document.
5. The experts are not necessarily proficient in the topic of probability. A training exercise at the start of the probability elicitation, including both individual and consensus stages (if present), is critical. The aim is to help them understand how they should think about and answer the questions. It is particularly important:
    a. that experts are comfortable giving their probabilities.
    b. to encourage them to recall any evidence they are aware of to inform their answer.
    c. to suggest experts think about betting odds/well known probabilities to help attach specific numbers to their expert intuitions.
    d. that, linked to point “b”, experts are providing useful rationales alongside their probabilities. These can be key when combining individuals’ probabilities.
6. Prior to any type of probability consensus discussion or strategy, the experts should input their probabilities **without** seeing the individual probabilities of any of the other experts.
    a. This is to avoid any type of “social” bias in which an individual feels pressured to change his/her/them answer because another one has a different opinion. Especially if there are hierarchical relationships between individuals (*e.g.* manager-subordinate)
7. Clarify every question with the experts prior to starting the individual elicitation. The definitions will likely need to be further tied down from the original version of the question.
    a. A textbook example (often used in training) is based on supposing the elicitation of “the distance between Edinburgh and Glasgow”. This sounds as a well-defined question, but some aspects still need clarification, such as:
        i. Measuring units (*e.g.,* kilometres vs miles)
        ii. Definition of distance (*e.g.,* as the crow flies/by road, etc.)
        iii. Definition of location (e.g. where in Glasgow and Edinburgh? The city centre? The city limits?)

8. In a CReDo context, the experts may not be able to give all of the probabilities that are required. For water assets, for example, failure or not will depend on local power assets which the water experts are not experts on.
9. It is advisable to not elicit too much on a single session. The focus should be on identifying the most critical probabilities to elicit in advance.
    a. When scaling up to hundreds of assets over multiple scenarios, then elicitation is not the go-to-tool for everything. Other strategies and methodologies should be considered on how to better scale model building.
    b. In CReDo phase 1 the team managed to elicit 7 probabilities in a 1.5-hour session. This is above average for the method that was used.
10. Concentrate on what the experts are saying during the session and/or the rationales provided. Sometimes the experts will not notice some critical element which will have a strong effect on the final probability.
    a. When running in person or online sessions, someone who is not facilitating the session should act as recorder, taking detailed notes of the discussion and rationales for the values chosen. These should be anonymised and then captured in writing.
    b. If running a more independent session (i.e. with no facilitator) make sure to encourage experts to provide reasonably detailed rationales. These could be used to follow-up with individuals if any problems or misunderstandings are identified.

Next steps

The CReDo team and the project partners believe that expert elicitation and Bayesian Networks models are a useful methodology to support the project short and medium-term ambitions. As such, these methodologies are the key focus of a number of ongoing and upcoming CReDo projects:

- **CReDo+ Extension to new climate risks** (Discovery stage – April 2023 to June 2023). Funded by the Strategic Innovation Fund (Ofgem), CReDo+ is a project that is focused on extending the use of the CReDo technology so that it can be used to obtain insights in relation to extreme heat events in the energy sector. Expert Elicitation methodologies are a key element of this project both for building asset models, but also in developing how to overcome some of the inherent limitations of the traditional methodology (as mentioned previously in this report) by considering the use of a digital elicitation tool. The CReDo team and project partners have now applied to “Alpha phase”; if successful this will enable the team to continue the work in this area from the last quarter of 2023 until March 2024.
- **CReDo Extreme Heat**, is a project funded by the Water Breakthrough Challenge 3 (catalyst stream) by Ofwat. Similarly to CReDo+, this regulator funded project is aimed at developing the CReDo technology for extreme heat events for the water industry. Expert Elicitation methodologies will be used to build asset models for this new use case. Both this and the previous project will seek to exploit synergies to maximise the impact of the work developed.

The CReDo team are aware that there are many innovative projects developing novel approaches to asset modelling in the space of climate resilience. The \ team has been in close contact with several of these projects and will seek to take advantage of any significant breakthroughs in this area. If you are interested in this work or in collaborating in the asset modelling area, please do feel free to contact the team via the DT Hub, Gemini Calls and/or directly over e-mail to credo@cp.catapult.org.uk.

References

1. **CReDo Technical Report 3: Assessing Asset Failure** - Public Resources - DT Hub Community (https://digitaltwinhub.co.uk/files/file/124-credo-technical-report-3-assessing-asset-failure/)

2. **CReDo+ Extension to new climate risks** – project overview documentation (https://smarter.energynetworks.org/projects/10061340/)

3. **CReDo+ Extension to new climate risks** – Show and Tell session (https://youtu.be/9uFqVnoeNGQ?si=sAV6o_8riQ4IL2-P)

4. **CReDo phase 2: developing decision support use cases report** (https://digitaltwinhub.co.uk/files/file/307-credo-phase-2-developing-decision-support-use-cases/)

Delivered in partnership with:

UKRI Innovate UK

econ FILMS

FATHOM

LUKE ANDREWS DESIGN

DAFNI

DIGITAL TWIN HUB

CMCL

CATAPULT Connected Places

UKRI Science and Technology Facilities Council

CReDo

Project partners

UK Power Networks Delivering your electricity

love every drop anglianwater

BT Group

frontier economics

THE UNIVERSITY of EDINBURGH

Newcastle University

WARWICK THE UNIVERSITY OF WARWICK

Acknowledging Phase 1 contributors

Centre for Digital Built Britain

Joint Centre for Excellence In Environmental Intelligence

Department for Business, Energy & Industrial Strategy

National Digital Twin Programme

Cambridge University

Crocodile Media

Mott MacDonald

ESRI UK