MINES Nantes

ISCH COST Action IS1304, Short term scientfic mission
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Scientific Report

1 Purpose of the STSM

The short term scientific mission (STSM) took place at the Delft University of Technology from October 10^{th} to 28^{th} under the guidance of Dr. Oswaldo Morales-Nàpoles. My PhD research encompasses the study of the reliability of assets in civil engineering using high-dimensional stochastic models. These models can desirably describe how large-scale networks behave in terms of degradation but need inputs which sometimes either cannot be obtained from field measurements or simply do not exist. For details on the considered probabilistic model we refer to Kosgodagan et al. [2016]. In order to overcome this, an expert elicitation borrowing from Cooke's method was carried out prior to the STSM. Three experts were solicited to answer the questionnaire. Consequently, the STSM application was mainly to execute the analysis of the elicitation outcomes :

1. performing the post-hoc analysis of the expert judgment, namely processing the inputs obtained from the elicitation and compute the various performance scorse as well as the decision makers'

2. examining how robust the elicitation is in terms of experts as well as seed variables. Robustness tests are brought forward as to measure how relevant experts or seed questions are, for instance if the majority of the experts fail to estimate one or more items.

This stay was also the occasion to present the results to the COST Action audience at the workshop for Asset and Project management organized in Delft, 12-14 October. The present research is very much in line with the topic of the workshop and it thus benefited of relevant feedback from the audience.

2 Content of the STSM

For the elicitation, the pool of experts consists of $E = \{1, 2, 3\}$ whose field of expertise is in the steel bridge management and reliability community, including various type of inspections and decision-making more generally. Experts answered a total of 24 questions of interest detailed in Table 1. We mention that items for Question 2 (V13 to V24) were not directly elicited as they appear in the table. Rather, out of a sample of size N, experts are asked to give a proportion of it. After answering the 12 seed questions and the 24 variables of interest, the estimates were processed in the EXCALIBUR software.

The combined distributions for the variables of interest taking into account the outcome on the robustness test are given in Fig. 1. The uncertainty intervals are narrower for the item weight DM, than for the other DMs. In spite of this, rather large uncertainties are expressed especially for variable V1, V4, V6, V7 and V10 for question 1 and for V14, V15, V18, V20, V21, V24. Specifically for V1, it reads that there is 0.9 probability that under a normal solicited load a moveable bridge would take between 3.09 and 49.45 years to transition between states 1 and 2, with a median equal to 21.62 years. We also observe that items regarding transition from state 1 to 2 (V1, V4, V7 and V10) show a great uncertainty interval compared to the other transitions asked to experts no matter the type of bridge nor its loading configuration. Similarly, V15 and V21 possess a larger uncertainty interval and have in common to address the exact same question that only differs in the type of bridge considered.

It is worth mentioning that the expert pool number here limits to three which claims to be rather small compared to surveys using Cooke's method Cooke and Goossens [2008] where the number of experts usually ranges from 4 to 45. A larger panel of experts should likely enrich current results by bringing together additional experts' knowledge to the current combined DMs. Concretely, it could also entail having one or more experts whose calibration score is greater than the cut-off level (0.05). Results are

Table 1: Variables of interest elicited as part of the expert opinion workshop aiming to quantify probabilistic inputs for the degradation of motorway orthotropic steel bridges.

Variable ID	Description	Variable ID	Description
Question 1	Expected duration (in years) to transition between the following condition states	Question 2	Probability that bridges transitioning to their next worse state conditional on a given load and state at previous time step for
	• under a normal load for		• a moveable bridge
	a moveable bridge		
V1	$1 \to 2$	V13	$P(M_t = 2 \vert M_{t-1} = 1, L_t = Normal)$
V2	$2 \to 3$	V14	$P(M_t = 3 \vert M_{t-1} = 2, L_t = Normal)$
V3	$3 \to 4$	V15	$P(M_t = 4 \vert M_{t-1} = 3, L_t = Normal)$
	a fixed bridge		
V4	$1 \to 2$	V16	$P(M_t = 2 \vert M_{t-1} = 1, L_t = Heavy)$
V5	$2 \to 3$	V17	$P(M_t = 3 \vert M_{t-1} = 2, L_t = Heavy)$
V6	$3 \to 4$	V18	$P(M_t = 4 \vert M_{t-1} = 3, L_t = Heavy)$
	• under a heavy load for		• a fixed bridge
	a moveable bridge		
V7	$1 \to 2$	V19	$P(M_t = 2 \vert M_{t-1} = 1, L_t = Normal)$
V8	$2 \to 3$	V20	$P(M_t = 3 \vert M_{t-1} = 2, L_t = Normal)$
V9	$3 \to 4$	V21	$P(M_t = 4 \vert M_{t-1} = 3, L_t = Normal)$
	a fixed bridge		
V10	$1 \to 2$	V22	$P(M_t = 2 \vert M_{t-1} = 1, L_t = Heavy)$
V11	$2 \to 3$	V23	$P(M_t = 3 \vert M_{t-1} = 2, L_t = Heavy)$
V12	$3 \to 4$	V24	$P(M_t = 4 \vert M_{t-1} = 3, L_t = Heavy)$

displayed Table 2 which is divided into two 'sub-tables'. Both show the calibration and information scores, the only difference is that the scores in the right table were computed after performing the robustness test leading to the removal of one seed question.

3 Outputs

The elicitation's outputs were used as inputs for a probabilistic model that describes how we can make predictions in terms of degradation for moveable and fixed steel bridges. Survival probability distributions, i.e. the probability that a bridge does not reach failure at a a certain time, were, amongst others, the main final outcomes of the model. The annual probability distribution to reach the worst state (state 4) using the item weight combined distribution are displayed in Fig. 2 for both moveable and fixed bridge categories. For each distribution the median (50^{th} quantile) is presented. Take "one minus this probability" at each time point and we obtain the aforementioned survival distribution.

The experts' outcome together with the probabilistic outputs are summarized in Kosgodagan et al. [2016]. The STSM turned out to be of utter importance in order to finalize this publication.

4 Future work/collaboration

Part of the current research is still concerned with high-dimensional modelling for large-scale networks of assets. However, an added layer corresponding to decision-making is being developed to account for policy making which deals with optimization as well. he general idea is to develop a time-varying copula-based non-parametric Bayesian network. To position this research w.r.t. current literature, there is a growing number of research material whose objective is to model multivariate times series through vines (undirected probabilistic graphs). Our objective is to use a different dependence framework through NPBN and assume for each of the time series to follow a fractional Brownian motion (fBM). It is a stochastic

Table 2: Results of the performance assessment for 3 experts and three different decision makers (DMs) were compared: the equal weight DM, the global weight DM, and item weight DM.

Expert ID	Calibration	Relative Information		Calibration	Relative Information	
		Total	Realization		Total	Realization
Exp. 1	2.7E-4	2.42	0.52	1.0E-3	2.42	0.35
Exp. 2	9.8E-5	1.79	1.21	8.3E-4	1.77	1.09
Exp. 3	6E-4	0.84	0.91	2.4E-3	0.80	0.80
Equal weight	0.446	0.445	0.36	0.825	0.410	0.244
Global weight	0.446	0.23	0.39	0.825	0.191	0.300
Item weight	0.446	1.093	0.49	0.825	1.021	0.431

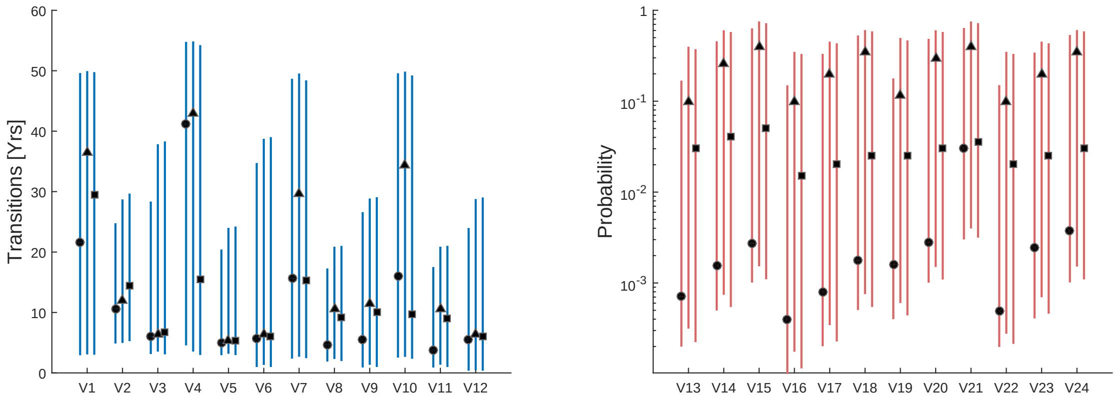

Figure 1: The decision makers distribution estimates expressed by the 5^{th} and 95^{th} percentiles through the segments lower and upper tips respectively, and the 50^{th} by the related symbol for the item weight (○), the global weight (△) and the equal weight (□).

process that mainly differs from the classic Brownian motion through the long-range dependency feature. In order to make this happen, one has to determine the so-called time copula describing the dependence of two different times for the process. This will then serve as the cascading blocks of bivariate copula that are describing the multivariate distribution.

This way and from recent research on dependence elicitation (see Morales-Nápoles et al. [2008], Werner et al. [2016]), eliciting conditional probabilities of exceedance and rank correlations would typically be of interest and would further incentivize future collaboration with Dr. Morales-Nàpoles using structured expert judgment.

References

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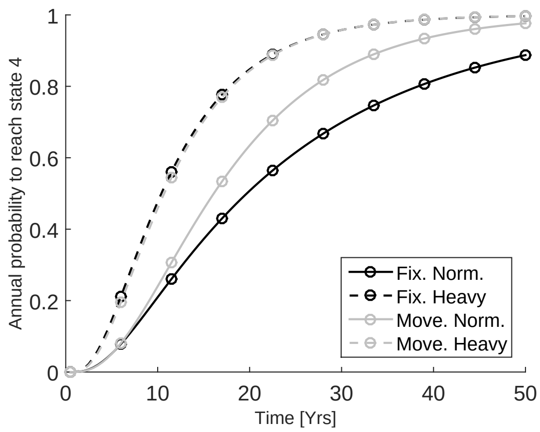

Figure 2: Performance based combination of the median estimate for annual probability distribution to reach worst state (state 4) for both Moveable *and* Fixed *bridges classes.*

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