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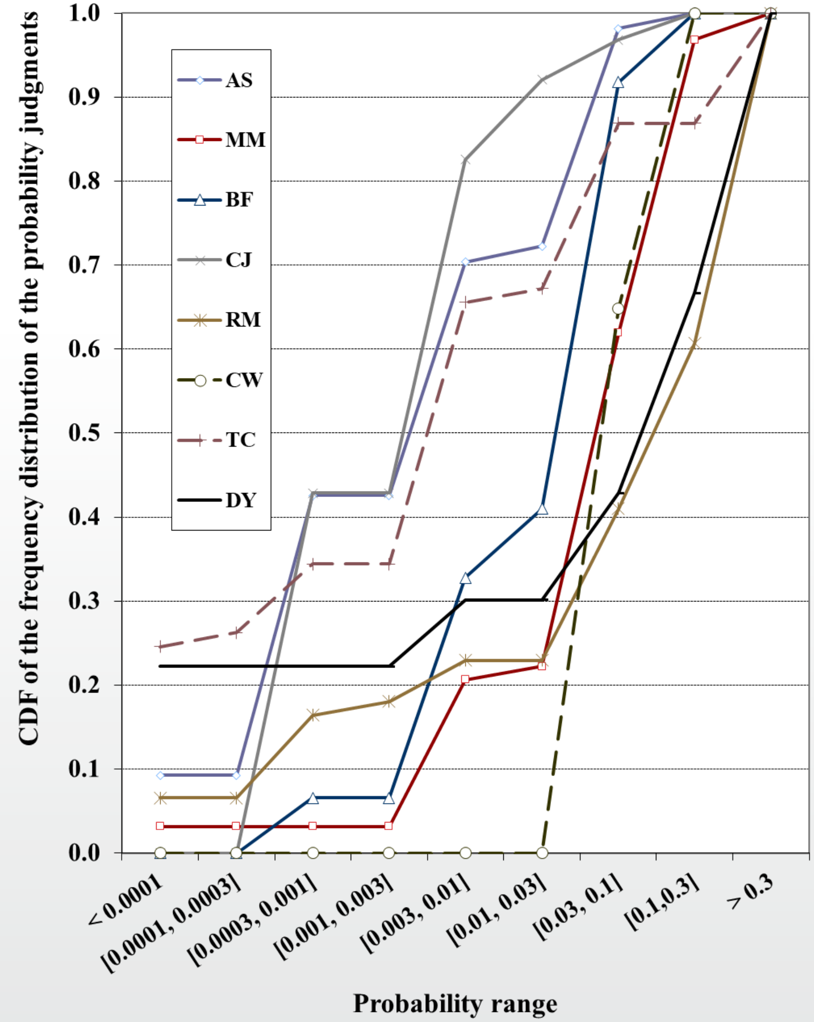
On the Reliability of Experts' Assessments for Autonomous Underwater Vehicle Risk of Loss Prediction: Are Optimists better than Pessimists?

Dr Mario P. Brito, Miss Yujia Chang
(absentia)
Centre for Risk Research
University of Southampton

Formal Expert Judgment Elicitation: concerns and objectives

1. Expert Judgment Elicitation(EEJ) is a process by which a facilitator elicits judgments from experts to identify and quantify risk and uncertainty in such a way the reduces the introduction of bias and enables reproducibility of the results.
2. The first studies in this subject were conducted in the US as part of the Nuclear regulatory foundation safety assessments
3. Formal expert judgment elicitation methods, such as the DELPHI method, the OTWAYs, EXCALIBUR, the SHELF-R consider different ways for aggregating expert judgments.
4. Debate still exists on the best way to aggregate expert judgments. Here we address the question:

Are optimists better than pessimists when we apply EEJ in the design stage?



Brito, M., Griffiths, G., & Challenor, P. (2010). Risk Analysis for Autonomous Underwater Vehicle Operations in Extreme Environments. Risk Analysis, 30(12), 1771-1788

Nereus–UI hybrid Autonomous Underwater Vehicles

The Woods Hole Oceanographic Institution has been awarded funds by the National Science Foundation to develop a tethered robotic underwater vehicle for under-ice exploration by 2014.

- **Acoustic communication.** By employing a novel light-weight tether for data-only communications, the vehicle will provide the U.S. Polar Research Community with a capability to tele-operate
- **Navigation.** under direct real-time human supervision, a remotely-controlled inspection and survey vehicle under fixed ice at ranges up to 20 km distant from a support ship or other deployment site. Under AUV mode, conventional navigation, dead-reckoning combined with INS.
- **Control systems.** Long-range light-fiber tether technology provides the high bandwidth link necessary for real-time control under the direction of the pilot.
- **Sensing.** A suite of chemical and physical sensors are deployed. Science sensors include Ph, CTD, water samplers, ADCP, image and acoustic (Yoerger et al, 2006)
- **Energy.** 16kW hours of rechargeable lithium-ion batteries, operation within suitable one atmosphere, pressure resistant housings.
- **Deployment and recovery.** The depressor is released first, containing the fiber optic tether followed by the AUV. For the recovery, uses a combination of acoustic and a catch system similar to the Nereus AUV.

NUI dive 2 launch on July 21, 2014. From German C. et al (2014) cruise report.

From Jakuba and Laney cruise report. August 2017

Bowen, A., et al (2009). The Nereus hybrid underwater robotic vehicle. *International Journal of the Society for Underwater Technology*, 28(3): 79- 89.

Yoerger, D.R., et al (2006). Autonomous and Remotely Operated Vehicle Technology for Hydrothermal Vent Discovery,

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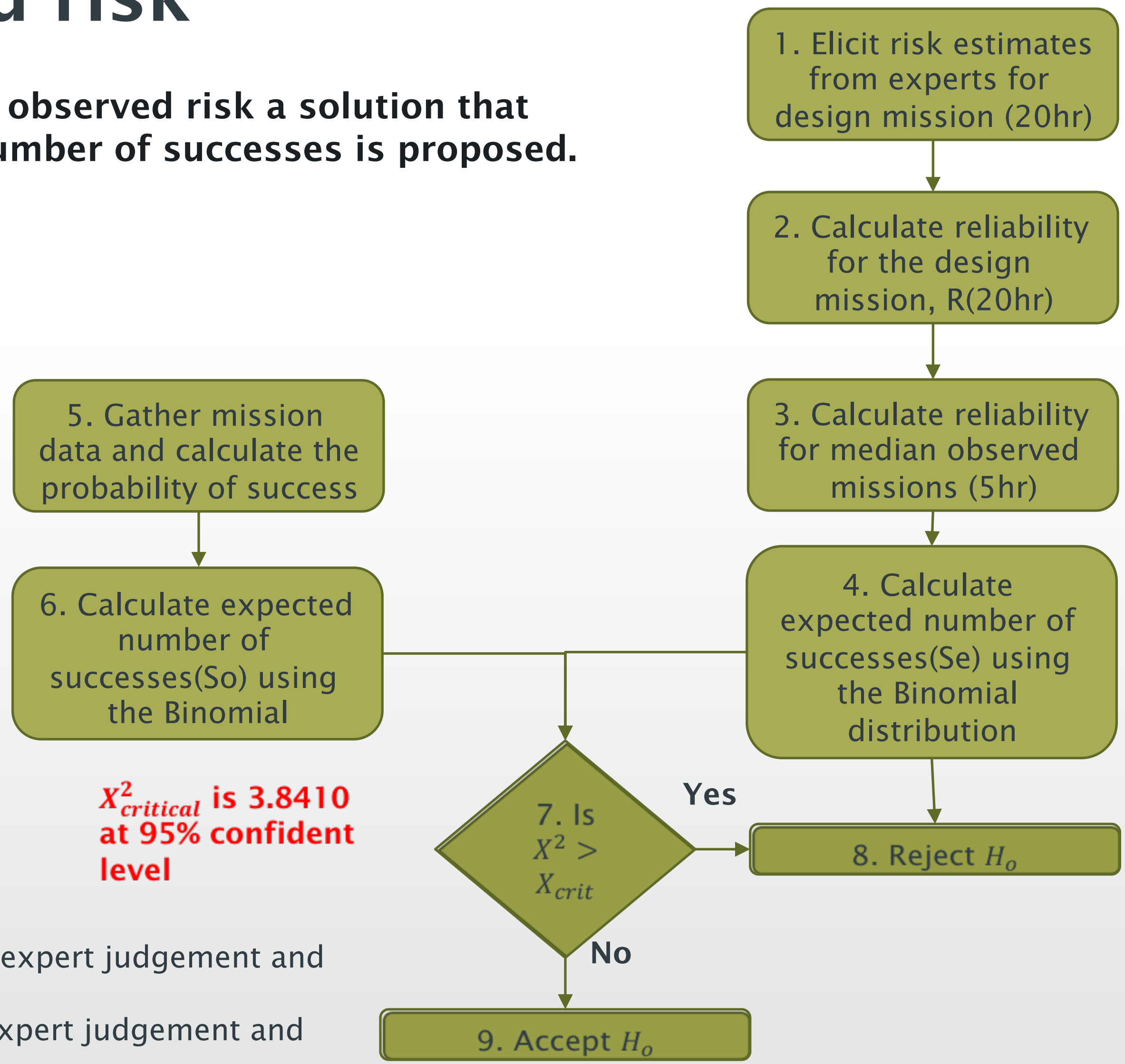
Method for comparing PRA expected risk against observed risk

To compare predicted risk with observed risk a solution that involves a comparison of the number of successes is proposed.

- **Expert judgment elicitation conducted using the EXCALIBUR method.** 5 experts took part in the risk assessment workshop in 2012. Markov chains and FTAs were agreed before the workshop.
- **Probability of loss for a 20hr mission calculated.** We assumed that the product would suffer early life failure. An exponential reliability model was adopted.
- **Binomial distribution.** The computed probability of loss informed the binomial distribution for 16 missions.
- **Non parametric test.** The X2 test was used for comparing the binomial distribution from observed data against observed distribution for PRA data.

  H_0: There is no difference between expert judgement and actual performance.

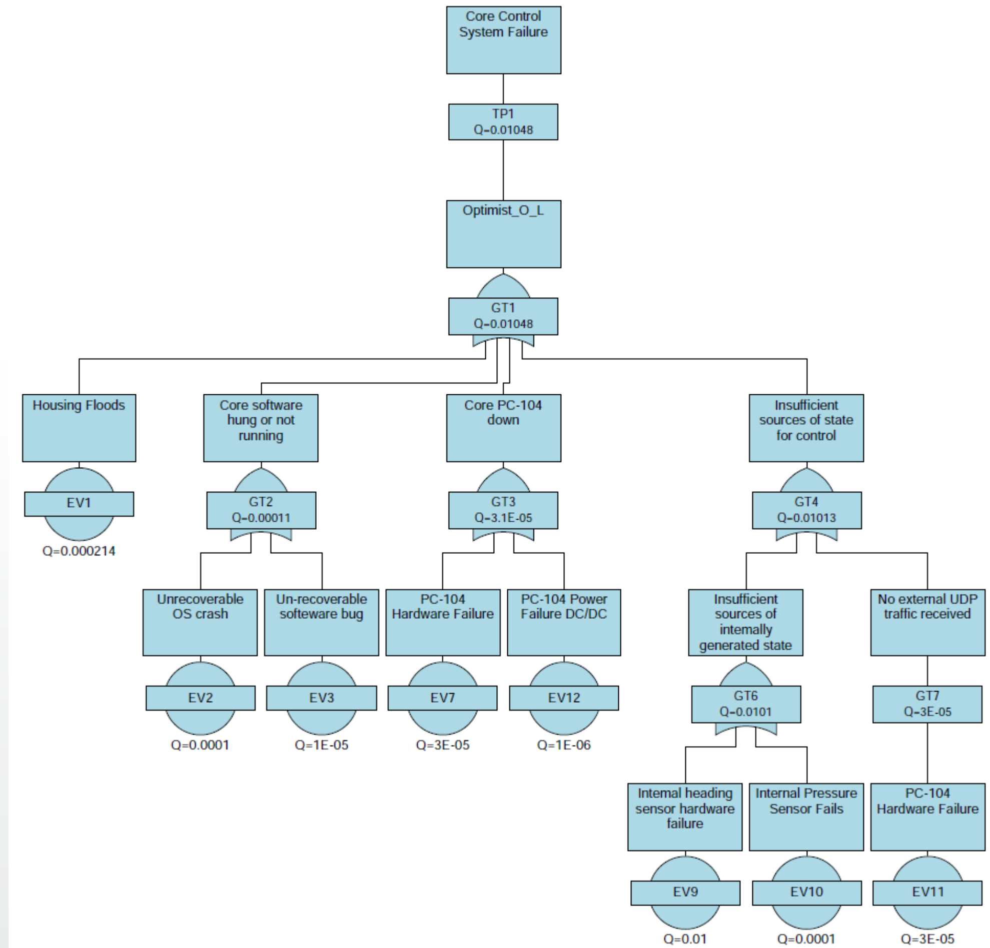
  H_1: There is a difference between expert judgement and actual performance.



$X^2_{critical}$ is 3.8410 at 95% confident level

A three stage expert judgment elicitation for HROV risk quantification

- Stage 1: Markov chain model capturing all stages of the HROV deployment. This stage focused on the operation and functional requirements (Brito and Griffiths, 2011)
- Stage 2: Fault tree modelling for quantifying the probability of loss for each transition in the Markov chain. The focus is on reliability with respect to vehicle loss. Failure is defined as vehicle loss. A fault may or may not lead to failure.
- Stage 3: Expert judgment elicitation. EXCALIBUR judgment was conducted. Workshop held in WHOI, 19th and 20th of June 2012. Five experts took part in the judgment elicitation. Experts were selected based on the their experience in under ice AUV missions. Ten seed questions were presented to the experts



Core Control System Failure fault tree model

Brito, M., & Griffiths, G. (2011). A Markov Chain state transition approach to establishing critical phases for AUV reliability. IEEE Journal of Oceanic Engineering, 36(1), 139-149

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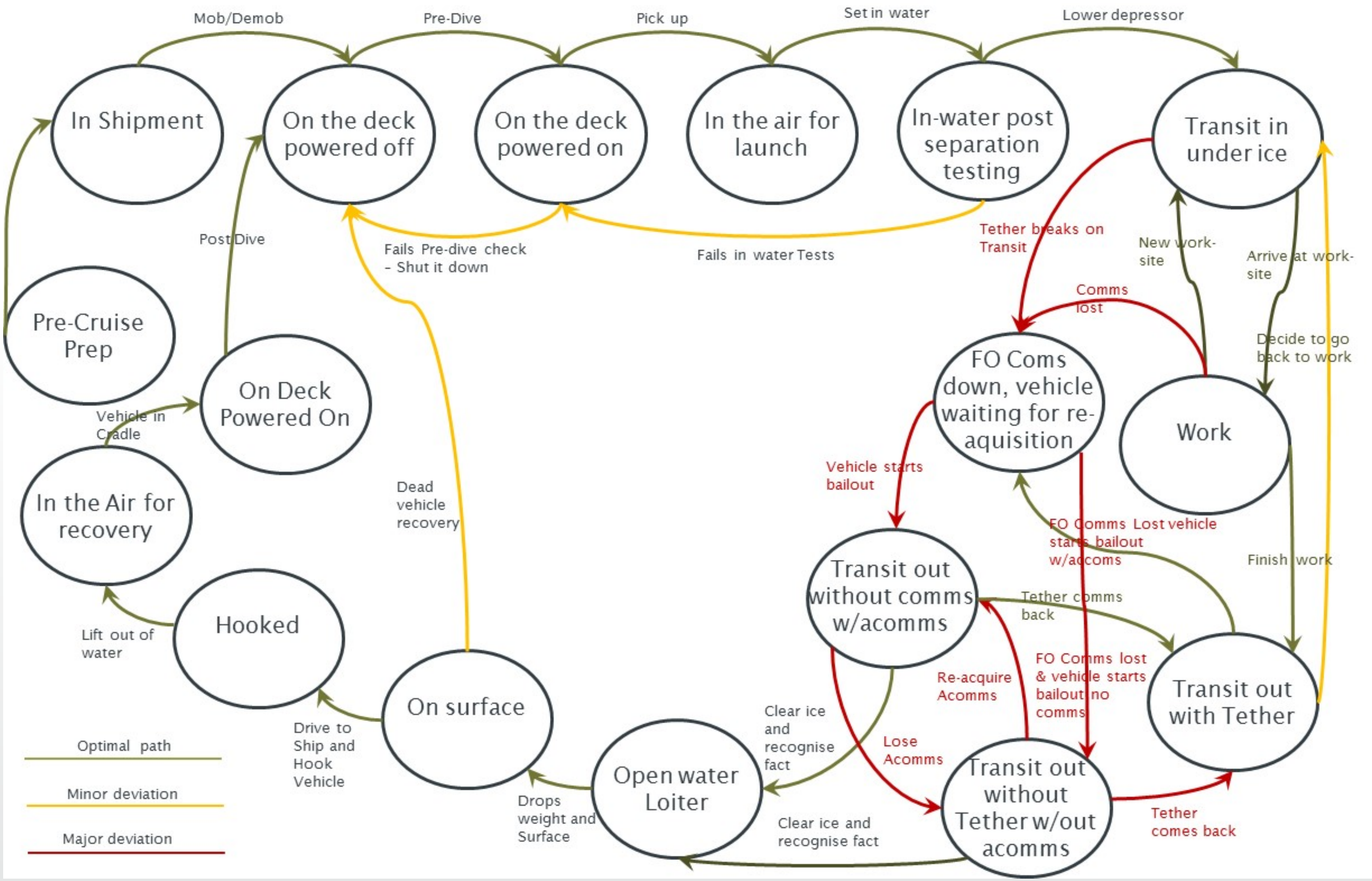
Three stage Expert Judgment Elicitation



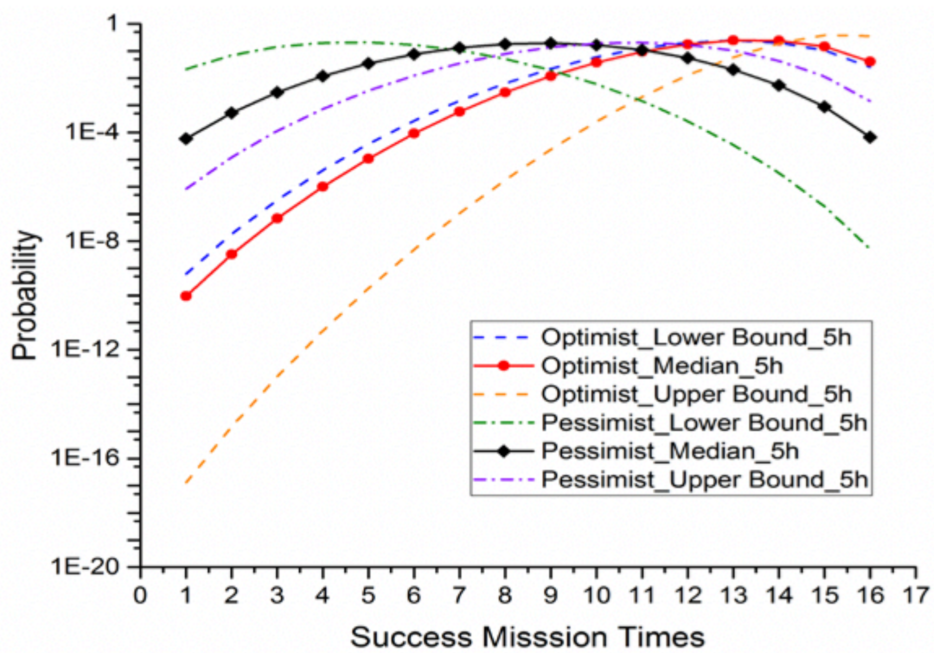
Expert judgment aggregation example

	Failure description				Experts				Experts
No		L	M	U		L	M	U	
8	Thruster Reliability	0.0002	0.0023	0.0045	SDM,JO, DY	0.0295	0.265	0.305	MJ,LB
9	Depth Sensor Reliability	0.0002	0.0005	0.00165	MJ,SDM ,JAN ,DY	0.009	0.01	0.011	LB
10	Phins Reliability	0.0002	0.002	0.0039	SDM,JA N,DY	0.0095	0.015	0.0555	MJ,LB
11	Microstrain Reliability	3.67E-0 5	0.0004	0.0018	SDM,JA N,DY	0.005	0.01	0.0305	MJ,LB

Risk model results…

	Optimists			Pessimists		
	L	M	U	L	M	U
Core Control System Failure	0.01048	0.02328	0.121	0.2486	0.2875	0.3956
PDS Failure	0.0001	0.0010	0.0030	0.0046	0.0075	0.0305
Battery Net Working	0.0203	0.0301	0.0404	0.1058	0.1667	0.3498
Dry Cable Failure	0.0001	0.0050	0.0100	0.0075	0.0150	0.0325
Vehicle Shape Changes	0.0176	0.0376	0.0501	**0.0936**	**0.1678**	**0.6639**
Bad-Wet-Connection	0.0107	0.0113	0.0118	0.2464	0.3080	0.3605
Housing Floods	0.0002	0.0014	0.0055	0.2383	0.2633	0.2876
Failed Electrical Board	0.0004	0.0013	0.0032	0.1304	0.1667	0.2329
OA Failure	0.0167	0.0220	0.0455	0.1376	0.2327	0.3531
Vehicle Stuck on Bottom	0.0029	0.0061	0.0202	**0.1388**	**0.1758**	**0.4621**
Vehicle Stuck on Underside of Ice	**0.1270**	**0.2401**	**0.3492**	0.1462	0.2680	0.3888
ROV Commands Bad Motion	0.0004	0.0014	0.0120	0.0224	0.0395	0.0443
FO Failure	**0.1340**	**0.1598**	**0.2738**	**0.4236**	**0.4996**	**0.5708**
Pilot Error	**0.0478**	**0.0870**	**0.1733**	**0.2049**	**0.3138**	**0.4377**
Transit in Underwater Ice	0.2280	0.5497	0.6004	0.8058	0.9097	0.9915

Maximizing the likelihood to find expected number of successes from PRA



	Optimists			Pessimists		
Number of missions	L	M	U	L	M	U
5	4.09E-06	1.00E-06	4.99E-12	2.01E-01	1.19E-02	7.33E-04
6	3.80E-05	1.09E-05	1.79E-10	2.10E-01	3.46E-02	3.47E-03
7	2.69E-04	9.07E-05	4.94E-09	1.68E-01	7.69E-02	1.26E-02
8	1.49E-03	5.87E-04	1.06E-07	1.05E-01	1.33E-01	3.55E-02
9	6.48E-03	2.99E-03	1.79E-06	5.14E-02	1.82E-01	7.90E-02
10	2.23E-02	1.20E-02	2.38E-05	1.99E-02	1.96E-01	1.38E-01
11	**6.03E-02**	**3.82E-02**	**2.50E-04**	6.08E-03	1.67E-01	1.92E-01
12	1.27E-01	9.43E-02	2.05E-03	1.45E-03	1.11E-01	2.07E-01
13	2.05E-01	1.78E-01	1.28E-02	**2.63E-04**	**5.59E-02**	**1.70E-01**
14	2.44E-01	2.48E-01	5.91E-02	3.52E-05	2.09E-02	1.04E-01

Maximum likelihood for: optimist = 13 expected successes expected successes out of 16 missions

Maximum likelihood for pessimists = 9 expected successes out of 16 missions

Field results and estimates of risk

The binomial distribution computes the probability of observing a given number of successes, r out of n experiments. Since the total number of missions carried out by Nereid UI was 16, we considered this as the total number of experiments. The binomial distribution is presented below.

$$P(x = r = 15) = \binom{n}{r} p^r (1-p)^{n-r} = 0.3798$$

where, n =1,...,16. P means the probability of success after n trial, the p is the probability of success in q single trial.

The expected number of successes = 0.3798*16 - 6

Results, conclusions, other findings and future work

- Optiomists v observed Xcrit = 20.1 (higher than Xcrit). Therefore we must reject the Null hypothesis. Differences between optimisits PRA and observed risk are statistical significant.

- Pessimits v observed Xcrit = 2.29 (lower than Xcrit). Therefore we cannot reject the Null hypothesis. Differences between pessimits PRA and observed risk are statistical significant.

- For Autosub 3 deployment under the Pine Island Glacier, the estimated probability of loss for scenario 1 was 0.33 (for the optimistic model) and 0.48 (for the pessimistic model). For the Nereid-UI AUV, the probability of loss for a 5h mission was estimated at 0.181 (for the optimistic model) and 0.452 (for the pessimistic model).

- We plan to extend this study as follows: we would like to assess the impact of the seed questions on the experts' performance. In this study we elicited the experts' judgements for 10 seed questions. We intend to use this data to provide further insight into the expert judgment elicitation process.

Thank you. Questions?

Dr. Mario Brito
m.p.brito@gmail.com