ADDING A BLACK-SCHOLES ROUTINE TO QUANTITATIVE RISK ASSESSMENT DECISION SUPPORT SYSTEMS

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1. INTRODUCTION

Vulnerability assessment focus groups are effective in gathering prioritized lists of risks but fall short of measuring communities' availability to support resilience and preservation plans for ecosystem services (Siriwardane, 2015). In the absence of this information, managers and planners risk facing resistance on essential\ plans and battle unnecessary delays in financing and decision-making.

These delays can cause serious consequences in the case of interconnected infrastructures, such as transport, telecommunication, water and energy services (Colton et al., 2012, Grafton et al., 2017). In fact, the increased resilience brought by interconnectivity also brings multiple ways for networks to fail.

Failure rates can change with time, trends in natural hazards and shifts in demographic pressures. In these cases, building resilience requires designing rapid responses for returning the systems into operation, for planning frequent updates and long-term reviews of refactoring efforts.

The concurrence of hard-to-predict changes in severe weather and the need for frequent adjustments in local resilience and adaptation plans create difficulties that can be alleviated by the availability of on-line decision support systems.

In this paper, the next section outlines the vulnerability assessment support system model we developed for the analysis of complex connected infrastructures called VUM-CREAM[2] (Coletti et al., 2013, Coletti et al., 2016). In the section after that, we describe forms of project financing based on the Black Sholes Morton options model that are being used with success to support the development of resilience plans. Lastly, we describe how the options model can be implemented in vulnerability assessment support systems of the VUM-CREAM type. The implementation method is based on the idea that resilience strategy posture of communities can be improved by discussions of *feasibility of viable plans on the base of climate data and concurrent observations of severe weather occurrences* (Geels et al. 2017, Rinaldi, 2001).

2. FROM VULNERABILITES TO RISK ASSESSMENT AND PLANNING

Since the development of the NOAA Community Vulnerability Assessment Tool [14] several attempts were made to apply information technologies to vulnerability assessments. Qualitative vulnerability assessments succeeded in exposing vulnerabilities of small communities that had otherwise difficulties in qualifying the problems they were having with utilities and services (Grafton et al., 2017, Coletti et al., 2013). Their inability to identifying point of failures in interconnected infrastructures led us to develop a model based solutions called Vulnerability Upper Model (VUM) that connected lower level elements failures to higher level system services (Coletti et al., 2013).

The use of ontology modeling for discovering interactions within elements from within a system, led to the development of a computational creativity approach (CREAtivity Machine- CREAM) where the risk discovery process is performed by the machine as a search process within the space of the VUM ontology (Figure 1). Since VUM is general and suitable for modeling a wide range of systems, CREAM can search hard-to-find point of failures within modeled interconnected infrastructures (Coletti et al., 2016).

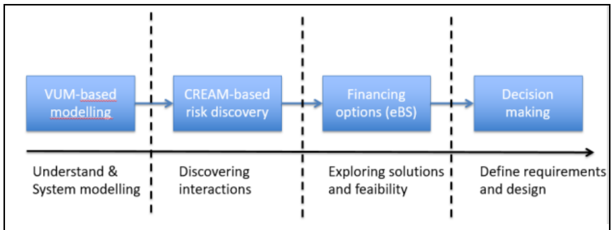

Figure 1: Proposed workflow process preceding plan design: vulnerability identification with system modeling (VUM); discovery of risks in interconnected systems (CREAM); assessment of communities' commitment to resilience plans efforts.

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[2] VUM-CREAM: Vulnerability Upper Model based-CREAtivity Machine

CREAM performs autonomic searches of logic nexus that can cause interconnected systems to fail and that may have been overlooked during requirement and design definition phases. It consists of a software application that generates new ideas (e.g., new risky situations) in the form of fragments of conceptual models. Based on computational creativity and semantic techniques, computational creativity is an emerging subfield of Artificial Intelligence devoted to defining computational systems capable of creating artifacts and ideas (Colton, 2012). CREAM links design patterns, as those derived from the VUM, with domain specific concepts. It exploits taxonomic reasoning and rules processing to infer new knowledge. The VUM – CREAM process demonstrated that by modeling the services provided by a system with an ontology, it is possible to analyze how low-level element failures can have cascading effects on higher level functionalities. As shown in (Figure 1), once risks are identified, the next step consists of reviewing the options available to improving resilience or survivability plans.

In the last few decades, the increasing frequency and severity of natural disasters is pressuring already financially stressed communities to search for short-term solutions possibly adjustable with time. Under these circumstances, there is a need to avoid delays and to accelerate approval of plans rapidly changing and adaptable. To minimize the unanticipated objections that may arise from communities at a late design definition stages of a plan, we propose a simple visualization tool of cost functions that can be used during early conceptualization of resilience plans. The tool measures relative differences in community's preferences toward early cost estimates of concept plans before further objections may arise during later phases of development.

The ability of comparing models, their benefits, and potential financing avenues empowers focus group participants by making them participants in the decision-making process. It may also stimulate useful discussions and maturation of ideas.

3. BLACK SCHOLES FOR OPTION FINANCING OF RESILIENCE PROJECTS

There are many applications using the Black Sholes options model for environmental plans (environmental Black Sholes (eBS). Examples of eBS range from protective measure of salmon farming in case of increase in sea water temperatures to the quantification of land transportation costs in the case of road ice melting for mining activities in Canada's northern latitude regions (Annan et al.2010, Grafton et al. 2017, Storm et al. 2017).

In all cases, the environmental options model quantifies the cost of a plan whose value changes at random and that, by a given date, it may exceed or fail expectations. Ecological applications of the eBS equation presumes that the variance of the distribution is known. It also assumes that any error due to change in the distribution of the random variable can be accounted for by simply multiplying the variance of a suitable factor.

The cost of a resilience plan estimated with the eBS may not necessarily be monetary. For example, it could be in the form of limits in fishing rates, food availability needs for the survival of endangered species, or in lines of code in computer programs in smart water management systems.

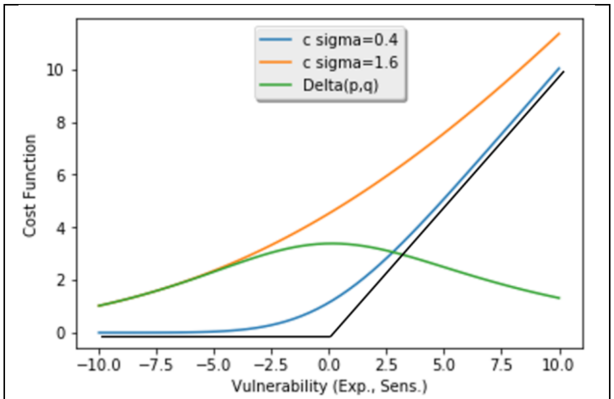

Figure 2: Cost functions computed with the eBS for different values of the variance (black, blue and orange lines). The black line is the cost function in the case of certainty (null variance). The difference between the two (green line) is the gain (or loss) in the safety margins realized by improving resilience from the low variance to the high one. A put option loss function diagram inverts left and right side of the call gain function around the center of the plot.

When eBS is used to finance resilience plans for weather or climate risks, the closing date for the financing contract can be determined by choosing a period within which a given condition can occur (call), or not occur (put). For example, a community interested in building a water reservoir could size the construction of a dam according to foreseeable drought events of given severity within 10 or 30 years. The drought severity threshold can be computed from the variance of past water flow data or equivalent measures. The eBS formula enables us to compute the cost of water as function of the need-availability ratio. The black line in Figure 2 illustrates the values of the cost function in case of certainty (null variance). When the water supply is greater than demand (negative vulnerability), the price is zero. The price of water increases linearly with demand when the supply decreases (vulnerability > 0). If instead the water source supply changes randomly and there is no reservoir, the price can increase around the anticipated mean of demand-supply. The orange and blue curves in Figure 2 show the results of the eBS simulations for different assumptions on the variance. The greater the variance, the higher the cost function moves along the vertical axis. If a water reservoir is built to protect against water source fluctuations within a certain factor of the variance, the savings realized in times of drought are quantified by the differences between cost functions (green curve in Figure 2).

This options model feature clearly visualizes how changes in the statistical properties of an environmental variable (mean value and variance) impact the cost of ownership of a system in focus group settings. If desired, eBS put function allows an estimate to be made about the cost function of events that are anticipated not to occur. In a put options, the left and right side of a call cost function are inverted because Call(V,0) = Put(0, V).

Theoretically, although several weather and climate parameters may not exhibit statistical distributions that meet the criteria needed for the applicability of the eBS formula, there is considerable amount of empirical evidence to show that eBS is robust in different types of random distribution [13]. Therefore, *the eBS equation can be regarded as a suitable means for enabling focus groups to visualize differences in remediation plans* and to express qualitative preferences on architectures of solutions before plans are designed.

The formal complexities of the Black Scholes equation notwithstanding, the formula simply computes the probability that a normally distributed variable may assume an anticipated value by a given time period. So, for example, in the case of focus groups, some participants may prefer to postpone certain resilience decisions even if others might consider them urgent. The different expectations can be used in the eBS to compute the cost functions for each preference.

4. MEASURING PREFERENCES IN PRELIMINARY RESILIENCE PLAN ASSESSMENTS

In a focus group setting, the use of an options model for the identification of viable remediation plans requires analysis of environmental past extremes along with statistics on climate trends (Grafton et al. 2017). As an example, Figure 3 compares the long term monthly averages of sea level rise (top) with the records of the sea level surges recorded (bottom) in Galveston (Texas). The two plots illustrate how both trends and surge information need to be considered in planning a 10 or 30 year long term resilience.

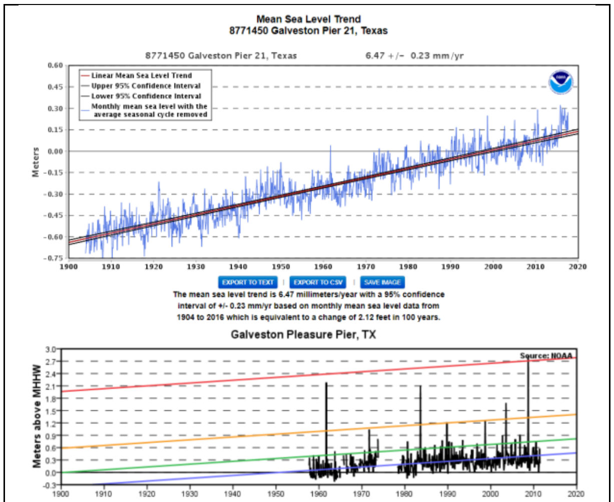

Figure 3: Sea level observations in Galveston. (top) monthly mean records, (bottom) extreme values. (Data Source: NOAA)

Therefore, while relatively reliable predictions can be made in the case of the slow trends (bottom graph in Figure 3), several competing strategies can be developed at the local level in conjunction with predictability of severe occurrences (top graph in Figure 3).

Generally, planners find it difficult to measure the preferences of communities toward the adaptation strategies they outline. For this reason, the eBS based process is being proposed for vulnerability assessments where traditional focus group management protocols can be followed by virtual project financing sessions. This is made possible by the reduced commitment online vulnerability assessments require from their participants.

Briefly, a focus group meeting can start with a fact-finding phase where the participants are presented with the reference material they need to review hazards and damage records of the past along with data that help them identify new potential vulnerabilities. The vulnerability discovery phase is followed by a survey of vulnerability prioritization that defines the needs that a remediation plan must satisfy.

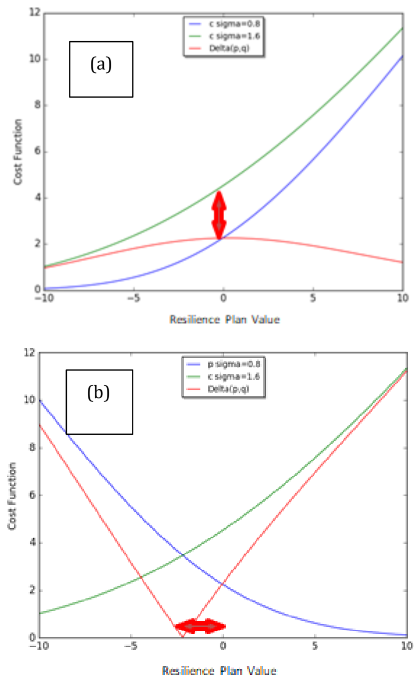

Figure 4: Options preference metrics computed with the eBS formula as call options. (a) The red vertical arrow displays the likely cost difference between two plans. Stakeholder preferences are measured by a voting system. (b) The horizontal red arrow measures the number of votes cast by a group of stakeholders favorable (call) or opposed (put) to a plan.

Depending on the scope of the focus group, this phase can be followed by a voting on one of two possible project financing scenarios. The first focuses on measuring the focus group preferences on two resilience plans designed for two different severity levels of likely scenarios (Figure 4a). The second (Figure 4b) measures the perceived urgency or procrastinating attitude toward the adoption of a single remedial action plan. In the (b) plot, the procrastinating vote for the plan is represented by a put option.
The red arrows in the figures illustrate the results of the measurements in the two cases. In Figure 4a, the vertical red arrow measures the different level of effort (value) the stakeholders are willing to spend for the two remediation plans. In Figure 4b the horizontal red arrow measures how strongly stakeholders feel about supporting projected preliminary estimated costs of a plan.

5. CONCLUSIONS

The use of the eBS formula-based visualization brings the attention of focus groups to their role in choosing among different fact-based available strategies against severe weather and climate threats. These simplified visualizations can be used to measure the support communities are willing to give to the remediation plans that are still in the preliminary phase of definition. In vulnerability assessments, the additional time required by this consensus building exercise can prevents later objections and potentially result in considerably greater time savings.
When coping with highly variable environmental threats, visualizations of cost function estimates for different solutions offer local communities the advantage of sharing their opinions with managers and planners more frequently and efficiently.
Pilot tests of the eBS options visualization method are under planning and will be performed among users of community water services.

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6. REFERENCES

1) Annan, James and Bowles, Justin and Bloch, Daniel Alexandre (2010): *Climate Hedging Explained. papers.* ssrn. com/sol3/ papers .cfm? abstract_id=1676146
2) Coletti, A. P. Howe, B. Yarnal, NJ Wood (2013): *A support system for assessing local vulnerability to weather and climate*, Natural hazards, 65, 999-1008. Springer
3) Coletti, A., A De Nicola, and ML Villani (2016): *Building climate change into risk assessments.* Natural Hazards, 84(2), 1307-1325, 1-19, DOI 10.1007/s11069-016-2487-6.

4) Coletti, A., A. De Nicola, M.L. Villani, (2017): *Enhancing Creativity in Risk Assessment of Complex Sociotechnical Systems*. ICCSA.
5) Colton, S., and G. A Wiggins (2012). *Computational creativity: The final frontier?* In Proc. of the 20th European conference on artificial intelligence, pages 21–26. IOS Press.
6) Geels, Frank W. and Sovacool, Benjamin K. and Schwanen, Tim and Sorrell, Steve (2017): *Sociotechnical transitions for deep decarbonization. Science*, 357, 242—1244,
7) Gersonius, B. (2012): *The resilience approach to climate adaptation applied for flood risk.* uuid:e519a730-dddb-49f3-b80c-252cfddb5b5b, **ISBN** 9780415624855
8) Grafton, R.Q., L.R. Little (2017): *Risk, Resilience, and Natural Resource Management: Lessons from Selected Findings*. Natural Resource Modeling, 30, 91-111.
9) Milly, P. C. D. et al. (2008) "*Stationarity Is Dead: Whither Water Management?"* Science, 319, p 573
10) Polsky C, Neff R, Yarnal B (2007) *Building comparable change vulnerability assessments: the Vulnerability Scoping Diagram.* Global Environmental Change 17:472–485
11) Rinaldi, S. M.; J. P. Peerenboom; T. K. Kelly (2001): *Identifying, understanding, and analyzing critical infrastructure interdependencies.* IEEE Control Systems. 21, 11 – 25.
12) Siriwardane, E. (2015): *The Probability of Rare Disasters: Estimation and Implications* Harvard Business School, Working Paper 16-061
13) Storm M., M.A. Goldstein, H. Huntington, and T.A. Douglas (2017) *Using an option pricing approach to evaluate strategic decision in a rapidly changing climate: Black Scholes and climate change*. Climatic Change, 140, 437 449.
14) Wang, Z, Peng Li, Lingyong Li, Chunyan Huang, and Min Liu (2015): *Modeling and Forecasting Average Temperature Derivative Pricing*. Advances in Meteorology, 2015, ID 837293, dx.doi.org/ 10.1155/2015/837293.
15) Watson (2009) *NOAA's Community Vulnerability Assessment Tool* in http://northeastarc.org/archive/2009/html/abstracts/nearc_watson01_20091004.pdf