The National Academies of SCIENCES ENGINEERING MEDICINE
GULF RESEARCH PROGRAM

Safer Offshore Energy Systems Grants 2
Final Report

Project Title: Collaborative Modeling with Fuzzy Cognitive Maps: A Novel Approach to Achieving Safety Culture
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I. ORIGINAL PROJECT SUMMARY (from proposal)

Research on high reliability organizations (HROs) has identified the factors that allow HROs to continuously foster safety culture and to quickly bounce back if an unexpected event occurs. However, because of the complex and abstract nature of HRO research, it is challenging to translate research insights into actions that are tailored to the conditions, needs, and constraints of specific organizations. Challenges include, but are not limited to: 1) adequate focus on reliability, so that it can reduce errors without being detrimental to initiative, 2) the design of communication and decision-making patterns that balance empowerment of all employees versus deference to deep expertise, 3) the incentive structures for reporting, rather than covering up errors, while simultaneously promoting error-free operations, and 4) deference to expertise without fostering so-called “prima donna” expert operators who undermine formal management authority.

Additional challenges in the oil and gas industry are the complexity of socio-technological systems which creates uncertainty about predicted system states, continuous production pressure, fatigue due to long work hours, reliance on temporary/contracted workforce for operations and response to disasters, increasingly virtual operations that make “on the ground” observation and culture building more challenging, and an industry culture that historically values toughness (i.e. roughnecks) and “can do” attitude over deliberation and analysis. As a result, many oil and gas operators still struggle with developing a safety culture that shapes all company processes and sustains itself, independent of individual players or specific initiatives.

To address this problem, the proposed research project will create (and evaluate with real world oil and gas industry actors) a novel toolset for scenario planning that is based on the system technique of Fuzzy Cognitive Map (FCM) modeling. It will allow decision-makers to explore, under different scenarios, the factors that contribute or hinder safety culture within their organizations in order to provide “double”

and “triple-loop” learning opportunities for lasting cultural change. To inform the design of the toolkit, the research will answer five research questions

1) How can the factors that contribute/impede safety culture in a specific organizational setting be modeled in a collaborative fashion?
2) How can FCM-based scenario planning be used to address uncertainty about external factors that impact safety culture?
3) How can exploratory FCM modeling and simulation be used to address uncertainty about the causal relationship between factors that contribute to safety culture?
4) How can results of exploratory FCM scenarios be analyzed and best be communicated to the collaborative modeling team?
5) Does collaborative FCM modeling impact key actors and decision-makers deeper understanding of drivers and barriers of safety culture and does this lead to actionable outcomes?

This research is exploratory: it is the first time application of collaborative FCM modeling to the topic of safety culture and the first collaborative FCM study that employs scenario planning and exploratory modeling strategies concurrently. If successful, the study will result in a modeling approach that can be used for localized, context-specific training for safety culture across a broad range of organizations.

II. PROJECT SUMMARY (final report)

Despite industry efforts to improve safety, accident rates in offshore oil and gas operations remain stubbornly high and frequently carry risks not only to workers, but also to ecosystems and communities. Practitioners often state that their work environment and culture are different from conditions in other industries and that improving safety will require customized approaches. In this project, we collaborated with industry practitioners to develop a model for safety culture that builds on known best practices from other industries and practitioner knowledge of the reality of offshore operations. The result is a simulation model that can be used to think through different safety improvement strategies, including those not commonly used in offshore oil and gas, and anticipate their likely impacts on different aspects of safety. Our work thus addresses a key obstacle to safety innovations - the concern that a novel safety intervention won’t work or have negative effects and that the effort might be better spent on doing “more of the same”. We found that many practices from other industries also apply to the offshore context. However, they need to be carefully selected and designed: when it comes to safety interventions too much of a good thing - such as training, incentives, management action - can actually make matters worse. We also identified approaches that are used in other industries, but are unlikely to improve safety in offshore operations. Our work helps managers prioritize safety interventions and design future safety training programs.

III. PROJECT RESULTS

Accomplishments

The project’s overarching objective was to facilitate the transfer of high reliability safety practices to the offshore oil and gas (O&G) industry. Such practices have been extensively researched (mostly qualitatively) in other industries with similarly complex and challenging environments, where they have been linked to the successful implementation of five major pillars of safety culture (deference to expertise, preoccupation with failure, reluctance to simplify, commitment to resilience, sensitivity to operations). Accordingly, major players in O&G industry are currently adopting these approaches.

Our project, however, focused on two aspects rarely discussed: 1) the unique social, technical and environmental context of O&G may cause some practices to deliver results that present unique challenges and therefore results when compared to other settings and 2) there are trade-offs between the often identified five pillars of safety culture, making it necessary to optimize rather than maximize all of them simultaneously. Further, there is a lack of empirical data on the implementation of these new practices in O&G, yet considerable expertise among practitioners that is not often considered. This (and the fact that safety culture consists of a system of interrelated factors) caused us to approach this challenge by creating a more informed system model of safety culture, based on published academic research and in collaboration with industry experts to integrate these various forms of expert knowledge.

The model uses Fuzzy Cognitive Maps and consists of two layers: its inner "core" describes the interdependencies between the many factors contributing to the five pillars of safety culture, based on published academic research. We created it based on thematic analysis of ca. 50 publications and, as part of the work, innovated a new way to extract edge strengths from textual data. The outer layer describes how the factors of the core model are impacted by safety practices specifically within the unique O&G context. This part of the model reflects the expertise of industry professionals, which we captured through a workshop and an online survey. The complete model that integrates these two forms of knowledge can be used to "run" scenarios and simulate how a combination of input factors impact safety culture as a whole. Input scenarios can reflect single and combined safety practices and external factors, as well as a combination of both. This can be used to identify impactful safety practices for O&G given different external conditions that are still unknown. Moreover, our work developed an approach to investigate uncertainty about model structure, using exploratory modeling. Ultimately, our work demonstrates how published academic research and industry expertise can be used in combination in order to provide data-informed, context specific models, and how these models can cope with uncertainty regarding external factors and system structure. We presented results to industry practitioners who reported having obtained new insights into the issues of safety culture, as well as initial guidance on how to improve culture.

In addition, our work resulted in several innovations and improvements of software tools, used for this research, including packages for FCM analysis and visualization in R (analysis and simulation) and in Python (exploratory modeling, visualization). The project also resulted in improvements to Mental Modeler online software (www.mentalmodeler.org) which was used for collaborative modeling. It is now being translated to Html 5 (away from Flash) so that the website can be more sustainable. All software products are free and can be used by researcher and scientists in a variety of disciplines.

Implications

Implication 1: Based on modeling results, we conclude that safety culture has to be addressed with a system perspective, rather than the common "do more of everything that might work" approach. Attempting to improve all five high reliability practice concurrently is, at best, wasteful because selective emphasis on a subset of combined safety interventions yields similar results. Even worse, it appears that some practices cannot be maximized concurrently and attempting to do so will yield poor or even negative and counterintuitive outcomes. Finally, some safety culture practices (e.g. encouraging prosocial behavior) might have other outcomes in O&G industry as compared to other settings. More empirical research is needed to investigate the phenomena identified in this study.

Implication 2: Modeling safety culture and interacting with a system model of safety culture is a worthwhile experience for experts and decision makers that leads to new and surprising insights for

them. Importantly, these modeling exercises can also be used to capture and synthesize industry knowledge that is currently mostly implicit. Future safety training programs in O&G should address high reliability (beyond the currently common compliance training) and should leverage system modeling for training and knowledge acquisition.

Implication 3: The method developed in this work is applicable beyond offshore O&G operations because it provides a general core model and an approach to contextualization. Results of this work can likely be used to improve safety culture in other critical industries in the Gulf region, including processing (e.g. oil refineries), fisheries, and health care. Future research in these settings could further validate the model and method, while addressing real-world challenges to community health.

Implication 4: Participants in this study were surprisingly capable of providing meaningful, formal descriptions of a complex socio-technical system (i.e., safety culture). This was possible because we did not require participants to share complete system descriptions but focused them on a manageable number of aspects, which we then wove into a complete picture through simple aggregation. The same approach seems feasible for obtaining descriptions of other (natural, human, technical) systems of interest in the Gulf region (fisheries, food chains, industries, etc). Given this potential, we investigated what aggregation approach is best for a "crowdsourcing" of system insights. Based on the results of our project, the team used an unrelated data set for this study (within a fisheries management context) which has been submitted to the journal "Nature". In addition to applying insights from this work to existing projects, we have also 'crowdsourced' from several experts (recreational fishermen, commercial fishermen and fisheries managers and scientists) to integrate these different forms of expertise to understand enigmatic questions such as how will predicted ocean warming influence fish stocks and fishing communities. Results of these two additional studies are very promising and future research should investigate crowdsourcing for managing natural resources and describing coupled natural-and human systems in the region.

Unexpected Results

At the start of the project, we had not yet planned to use "thematic proximity coefficient" for extracting edge weights for FCM. We created this approach, based on a June 2017 publication we came across. It turned out to be a very reliable and traceable approach to creating FCM models from the literature. We also had expected the safety culture model to be more sensitive to a larger number of edge weights, resulting in a need for extensive exploratory modeling. Taken together, these two somewhat unexpected results have led to a more efficient and robust method for model creation.

Project Relevance

Researchers, federal government officials, the non-profit private sector, and the for-profit private sector would be interested in the results of this project.

Our work contributes to safety culture research by providing an approach to modeling the elusive concept of safety culture. This is of interest to researchers, federal agencies including regulators, and industry organizations aiming to improve safety practices. Moreover, industry practitioners will be interested in the implications for their companies.

Moreover, our works has resulted in considerable innovations in collaborative system modeling, which should be of great interest to researchers in many fields, including system modeling, natural resource management, participatory assessment, and community engagement. This work provides tools and

methods to support more inclusive decision-making and growing research paradigms in public participation in research and participatory modeling (PM). The popularity of PM has grown considerably in recent years. It is widely acknowledged that the broad inclusion of stakeholders and different scientific perspectives are required to improve our understanding of complex environmental or social problems.

Currently, a wide range of stakeholder-centered modeling tools and approaches exist, that all aim to provide decision support and facilitate participatory planning contexts to varying degrees. Although the application of these tools has recently experienced a large increase, some critics have cautioned that diversity of modeling practices does not necessarily indicate diversity in function, and many stakeholder modeling platforms are often prone to duplication of effort. Our work provides considerable new insight into how such PM can be scaled up to address a particular issue across an array of decision-making cultures.

Education and Training

Number of students, postdoctoral scholars, or educational components involved in the project:

- Undergraduate students: 0
- Graduate students: 6
- Postdoctoral scholars: 0
- Other educational components: 0

IV. DATA AND INFORMATION PRODUCTS

This project produced data and information products of the following types:

- Scholarly publications, reports or monographs, workshop summary or conference proceedings
- Websites or data portals
- Models and simulations
- Software packages or digital tools, or other interactive media

Data Products

Description of data sets:
There are two data sets are listed in the data reporting table - both contain practitioner judgements about the causal connections (direction, sign, strength) between safety culture interventions and concepts in the core model. Data set 1 was created in a workshop, Data set 2 through an online survey.

Information Products

Citations for project publications, reports and monographs, and workshop and conference proceedings:

Project results were presented at 1) a workshop and 2) the annual meeting of the Center for Offshore Safety, at 3) iEMSS 2018 (International Environmental Modelling and Software - two presentations and peer-reviewed papers), and at 4) INFORMS 2018. They are listed in the “information products” table. None of these publications were cited yet. Additional publications are in preparation.

V. PUBLIC INTEREST

Most Unique or Innovative Aspect of the Project

This project is novel in several ways: Many researchers and industry practitioners accept that safety culture is complicated, constantly evolving and extremely difficult to measure and claim that it is therefore (almost) impossible to manage directly. Our project takes a different stance. By using a technique not yet used in safety research (Fuzzy Cognitive Map modeling) we present the many factors that determine safety culture as a system model. Our unique approach allows safety managers to simulate the outcomes of their decisions before implementing them in the real world. Moreover, the project integrates two knowledge sources - academic research and industry practitioners' first hand experiences - thus overcoming silos that can impede safety improvements.

Most Exciting or Surprising Thing Learned During the Project

We were surprised how quickly we were able to create a robust model of safety culture by combining published research and industry knowledge. This collaborative modeling method is likely applicable to many other complex problems.

Most Important Outcome or Benefit of Project

Our project is exploratory and demonstrates the overall feasibility of a novel approach for thinking about safety culture. We hope that our results will provide the foundation for innovative safety culture training programs that will improve the health and safety of offshore oil and gas workers and reduce the number of critical incidents that can put communities and ecosystems at risk.

Data Report

DataType	DigitalResourceType	Title	FileName	Creators	PointofContact	PublicationYear	RepositoryName	DOIorPersistentURL	Keywords	Publications
Social/Cultural	Tabular/Spreadsheet	Workshop Data Input	Houston Workshop.csv	Jetter, Antonie; Gray, Steven; Scyphers, Steven; Alibage, Ahmed;Aminpour, Payam	Project Principle Investigator ajetter@pdx.edu 503-725-4663	2018	Northeastern University Digital Repository Service	TBD	HRT, HROs, Offshore Oil and Gas, Gulf Project	N/A
Social/Cultural	Tabular/Spreadsheet	Oil and Gas Survey	Gulf Project Survey.csv	Jetter, Antonie; Scyphers, Steven; Alibage, Ahmed;	Project Principle Investigator ajetter@pdx.edu 503-725-4663	2019	Northeastern University Digital Repository Service	TBD	HRT, HROs, Offshore Oil and Gas, Gulf Project	N/A

Information Products Report

InfoProductType	DigitalResourceType	Title	FileName	Creators	PublicationYear	Publisher	RepositoryName	DOIorPersistentURL	DatasetReference
Workshop or Conference Proceeding	Text	Workshop Brochure	Practical approaches to safety culture: A workshop for knowledge exchange, model building, and planning.pdf	Alibage, Ahmed; Jetter, Antonie; Gray, Steven; Scyphers, Steven; Aminpour, Payam	2018	Portland State University	Northeastern University Digital Repository Service	TBD	TBD
Workshop or Conference Proceeding	Text	iEMSs 2018 Proceedings	Exploratory Participatory Modelling with FCM to Overcome Uncertainty: Improving Safety Culture in Oil and Gas Operations.pdf	Alibage, Ahmed; Jetter, Antonie; Gray, Steven; Scyphers, Steven; Aminpour, Payam	2018	International Environmental Modelling and Software Society	9th International Congress On Environmental Modelling And Software - Ft. Collins, Colorado, Usa - June 2018	https://scholarsarchive.byu.edu/iemssconference/2018/	
Workshop or Conference Proceeding	Text	iEMSs 2018 Proceedings	Open source tool in R language to estimate the inference of the Fuzzy Cognitive Map in environmental decision making.pdf	Papageorgiou, Elpiniki; Jetter, Antonie; Dikopoulou, Zoumpolia; Bochtis, Dionysios	2018	International Environmental Modelling and Software Society	9th International Congress On Environmental Modelling And Software - Ft. Collins, Colorado, Usa - June 2018	https://scholarsarchive.byu.edu/iemssconference/2018/	
Models and Simulations	Other Resource Type	HRT-FCM Model	HRT-FCM Model.xlsx	Alibage, Ahmed; Jetter, Antonie	2018	Portland State University	Northeastern University Digital Repository Service	TBD	TBD
Models and Simulations	Software and Source Code	FCM python package	PyFCM (Python for Fuzzy Cognitive Mapping).py	Aminpour, Payam	2018	GitHub	payamaminpour/pyFCM	https://github.com/payamaminpour/PyFCM/wiki	
Models and Simulations	Software and Source Code	Inference of Fuzzy Cognitive Maps (FCMs)	The fcm package.html	Dikopoulou, Zoumpoulia; Papageorgiou, Elpiniki	2018	CRAN	packages/fcm/vignettes/vignettes.html	https://cran.r-project.org/web/packages/fcm/vignettes/vignettes.html	
Workshop or Conference Proceeding	Text	Participtory Modeling	A Participatory Model for Improving Safety Culture in Oil and Gas Operations.pdf	Jetter, Antonie; Alibage, Ahmed	2018	INFORM Annual Meeting 2018	pp8/#!/4701/presentation/6835	http://www.abstractsonline.com/pp8/#!/4701/presentation/6835	
Models and Simulations	Web Based Resource	Offshore Oil and Gas Oinline Survey Questions	Gulf Project Survey.pdf	Jetter, Antonie; Scyphers, Steven; Alibage, Ahmed;	2019	Portland State University	Northeastern University Digital Repository Service	TBD	TBD
Models and Simulations	Image	HRT-FCM Simulations	HRT-FCM Simulation Package.pdf	Aminpour, Payam	2019	Portland State University	Northeastern University Digital Repository Service	TBD	TBD