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研究課題名(和文) "Natech-RateME" Comprehensive Natech Performance Rating System for industrial Parks to Manage Risks from Extreme Events: Framework Development and Testing

研究課題名(英文) Natech-RateME" Comprehensive Natech Performance Rating System for industrial Parks to Manage Risks from Extreme Events: Framework Development and Testing

研究代表者

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研究成果の概要(和文)：自然災害によって引き起こされる化学事故(Natech)の工業地域への影響のリスクを評価し管理するために、総合的なリスク管理および性能評価を行うシステムを開発しました。データベースからNatech事故を抽出するためにセミインテリジェントな枠組みをもつ機械学習を開発し、リスク要因をマッピングして分析しました。1990年から2017年まで、およびIPCCのいくつかの将来のシナリオの下で、米国における熱帯暴風雨に関連したNatechの確率を推定し、増加傾向を確認しました。国内外のNatechのフィールド調査と多様な関係者の会議を通じて、調査結果を修正し、共有しました。

研究成果の学術的意義や社会的意義

The development of the Natech RateMe framework that incorporates ideas of resilience engineering, and proposes a paradigm shift. Risk communication and participatory risk governance are main elements yielding immediate benefits for disaster preparedness, while cultivating a cooperative climate.

研究成果の概要(英文)：A comprehensive risk management and performance rating system was developed to assess and manage the risk at industrial parks due to natural hazard triggered chemical accidents (Natechs). A machine learning semi-intelligent framework to extract Natech accident from large databases was developed, and we used graph theory to map and analyze risk factors in the Natech event chains. We investigated the temporal-spatial variation of the incidence of tropical storms-related Natechs, and the accumulated cyclone energy and other variables, suggesting an indirect link between climate change and the incidence of Natechs. Also, an empirical estimation of the probability of tropical storm-related Natechs in the United States from 1990 to 2017, and for several IPCC future scenarios was carried out, confirming an increasing trend. Finally, through field investigations of Natechs in Japan and abroad, and through multistakeholder meetings the results of the research were validated and disseminated.

研究分野：Chemical engineering, disaster risk management

キーワード：Risk management Natech Disaster prevention Industry Chemical accidents Rating systems Area-wide Resilience

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様式 C - 19、F - 19 - 1、Z - 19 (共通)

1. 研究開始当初の背景

Natural hazard forces can act on large areas causing damage to industrial facilities often triggering hazardous materials releases endangering nearby communities. These events are known as Natechs. The frequency and severity of Natechs may be increasing due to industrialization and urbanization, and possibly climate change (OECD 2012, 2015; Cruz and Krausmann 2013; Krausmann et al. 2017). Despite efforts to consider natural hazard loads in the design and construction of industrial facilities and to ensure industrial safety, natural hazards are not part of process hazard and risk assessment resulting in inadequate assumptions concerning safety barriers as well as gaps in emergency planning. Furthermore, because natural hazard events may affect large areas simultaneously, the risk management of Natechs requires broadening the scope of risk assessments from individual firms to industrial agglomerated areas and neighboring communities. There are however no methodologies proposed for area-wide risk assessment and management of Natechs. In addition to area-wide risk assessment, a way to systematically rate improvements towards risk reduction goals is required to monitor performance and evaluate progress, for the purpose of strengthening business continuity and territorial resilience.

2. 研究の目的

The main goal of this research study is to develop a comprehensive Natech performance rating system for industrial parks to assess and manage the onsite and offsite risk from extreme events, in order to increase territorial resilience. To achieve this goal, we proposed four main objectives including a review of existing rating systems in different fields; the review and benchmarking of industrial and Natech risk assessment methodologies in order to identify good practices and extend their use to area-wide analysis; the review of past accidents to identify risk factors in the chain of events, as well as identify possible barriers or countermeasures for risk reduction; and the identification of performance objectives and evaluation criteria in order to propose a new area-wide comprehensive Natech performance rating system. In addition to the above objectives, through several multi-stakeholder workshops, and field case studies, the framework components were tested and validated, and the results of the study were disseminated to a wider audience including other researchers, industrial facility operators, and local community members.

3. 研究の方法

(1) Systematic literature review of past research and available rating systems frameworks to support the development of the Natech-RateMe system

We carry out a systematic literature review and published a review paper on the advances in Natech research from for the past 40 years. Many methodologies, rating systems and tools were reviewed serving as the foundation for the study

(2) Natech event data collection and analysis

Due to data scarcity and high uncertainty, identifying Natech accidents from chemical accident databases is a challenge. We used machine learning theory, to solve the problem. Also, we analyzed the temporal and spatial variation of tropical storm-related Natechs (TSNatech) through various methods including the Mann-Kendall Trend Test, Wavelet Analysis methods, and the Intensity Analysis method. A Cross-wavelet analysis method was used to analyze the correlation and coherence characteristics between climatic indices and the number of TSNatechs.

(3) Analysis of risk factors of Natech event chains and benchmarking of accident investigation methodologies

We used network modeling and probabilistic network analysis to identify risk factors which can trigger TSNatechs based on the analysis of their event chains. Network diagrams were developed by combining all, or subsets of the event chains. After developing the network diagram, probabilistic network analysis was conducted. Furthermore, we benchmarked several accident investigation methodologies applied to two case studies in Japan.

(4) Field visits in Japan and abroad

Data collection was also carried out through field visits, surveys and interviews with various stakeholders including industry and government officials, and citizens.

(5) Meetings, workshops, and conferences

We have conducted a series of meetings, workshops, and conferences which served to provide input for the framework development and validation, as well as served to disseminate the research findings, and the academic and greater social contributions of the project.

4. 研究成果

(1) Systematic literature review and qualitative meta-analysis of Natech research

The systematic literature review provided the main basis for the study. The findings reflected the increasing awareness in the research community of the necessity to have an all-inclusive understanding of hazards in order to properly deal with the threats posed by Natech risk. As main contributions, we published two peer reviewed articles. One is a systematic literature review, and the other from a more theoretical perspective, presents an analysis of the recent history and current state of Natech risk management, identifying the main gaps in both the theoretical understanding and the practical implementation thereof, and propose ways forward for the development of new research, and the need for paradigm shift in industrial risk management (Suarez-Paba *et al.* 2019, and Cruz and Suarez-Paba 2019).

(2) Extracting Natech Reports from Large Databases: Development of a Semi-Intelligent Natech Identification Framework (SINIF)

We tested the suitability of two supervised machine learning algorithms, and developed the SINIF. According to the results, the SINIF is efficient (a total number of 826,078 records were analyzed) and accurate (the accuracy is over 0.90), while 32,841 Natech reports between 1990 and 2017 were extracted from the NRC database. Furthermore, the majority of those Natech reports (97.85%) were related to meteorological phenomena, with hurricanes (24.41%), heavy rains (19.27%), and storms (18.29%) as the main causes of these reported Natechs. Overall, this study suggests that risk managers can benefit immensely from SINIF in analyzing Natech data from large databases efficiently. This work resulted in a peer reviewed publication (Luo *et al.* 2020).

(3) Climate Change and Temporal-spatial Variation of Tropical Storm-related Natechs in the United States from 1990 to 2017: Is There a Link?

This study analyzed the temporal-spatial variation of tropical storms-related Natech incidence in the United States (US) from 1990 to 2017 based on the analysis of hazmat-release accidents reported to the US National Response Center (NRC) database. The results show that the frequency and density of tropical storms-related Natechs are on the rise. We investigated the relationships between the temporal-spatial variation of the incidence of tropical storms-related Natechs, and the accumulated cyclone energy, and other variables. The results suggest an indirect link between climate change and the incidence of related Natechs. The presented evidence suggests that, when developing Natech risk management plans, the potential effects of climate change should be considered. This work has been published in a peer reviewed journal (Luo *et al.* 2021)

(4) Analysis of risk factors of Natech event chains

With colleagues from Hiroshima University, we proposed a probabilistic network modeling approach in which the inherent characteristics of risk factors for consumer-level gas incidents were considered. In the approach, cause-effect chains are formulated for gas incidents, and network diagrams with probabilistic estimations are constructed. The investigation shows that most gas incidents are caused by more than one risk factor, and one risk factor tends to cascade into others. These risk factors can be clustered according to their nature and can also be classified as originating causes or intermediate risk factors by analyzing their interdependencies in network diagrams. By identifying significant intermediate effects together with their causes, these risk factors can be reduced, which may reduce the occurrence of serious gas incidents at the consumer level. Furthermore, using data from the NRC database and others, we analyzed tropical storm related Natech event chains. Based on the results, countermeasures targeted at risk factors that have high occurrence probability were recommended. Several publications using the developed approach have been published (Lam and Cruz 2019, Lam *et al.* 2021).

(5) Benchmarking of accident investigation methodologies

Several accident investigation methodologies were benchmarked. The investigation used two Natech accidents that occurred during the Great Japan earthquake and tsunami in 2011. The evaluation results established that not one methodology can satisfactorily analyze an accident as complex as a Natech event. A general approach to select the investigation methodology is discussed. This work was published in a peer reviewed journal (Chakrabortya *et al.* 2018). Furthermore, the results were included in a report

by the European Commission's Joint Research Centre in Italy (results appear in: Allford and Wood 2021).

(6) Natech accidents and risk management in Colombia and Japan

Field work for the study was carried out in Japan and abroad. Due to difficulties in reaching out to industrial partners in Japan, part of the research was carried out in Colombia. We worked with the three important chemical and petrochemical companies, several industry associations in Medellin and Bogota, with local, regional and national government, and other important stakeholders in the development and validation stages of the Natech-RateMe framework. Our work in Colombia is ongoing, and the partners participated in the final project symposium held in March 2021. A publication based on this work have been published (Suarez-Paba et al. 2020a, 2020b), and second one is under review (Suarez-Paba and Cruz 2021). In addition, we investigated Natech accidents that occurred in Japan in 2018, 2019 and 2020. Furthermore, interviews, focus groups and workshops were carried out with various stakeholders including local government, prefecture government, fire departments, and citizens affected by Natech accidents which confirmed again and again the need and validity of the Natech-RateMe framework and its components. A peer reviewed publication was published (Araki *et al.* 2021), and another is under review (Misuri et al. 2021).

(7) Natech-RateMe Framework and Rating System

The comprehensive area-wide risk management and rating system framework, entitled "Natech-RateMe, was developed in order to evaluate the level of performance of industry when faced with Natech scenarios while through the risk management process the framework enhances territorial resilience. By looking at both the industrial facilities and their interaction with the external environment, we proposed a paradigm shift in Natech risk management to address Natech risk more effectively and to improve local stakeholders' ability to manage their own risks. The performance rating system, is premised on a probabilistic risk assessment methodology, to quantify the expected number of fatalities per year that may result from accidental hazardous materials releases triggered by earthquakes. In addition, the framework provides a systematic way to analyze industrial facilities vulnerability to natural hazards, and the prevention and mitigation measures that can be adopted to improve territorial resilience to these types of risks. The main theoretical contribution of the study lies in the proposed paradigm shift that calls for "comprehensive and integrated" Natech risk management and risk governance not of individual facilities, but of the territory where they are located, incorporating the notions of resilience engineering, and the analysis of the interconnections between organizational, infrastructural, environmental and community resilience to efficiently manage inherently risky systems. A paper based on this work has been published (Suarez-Paba et al. 2020b), and a second paper is currently under review (Suarez-Paba and Cruz 2021).

< 引用文献 >

- Allford, L. and Wood, M. (2021). Accident Analysis Benchmarking Exercise, *EUR 30564 EN*, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-28605-9, doi:10.2760/08034, JRC123513.
- Araki, Y., Hokugo, A., Pinheiro, Abel.Tá.Konno., Ohtsu, N., Cruz, A.M. (2021). Explosion at an aluminum factory caused by the July 2018 Japan floods: Investigation of damages and evacuation activities, *Journal of Loss Prevention in the Process Industries*, Volume 69, March: 104352, <https://doi.org/10.1016/j.jip.2020.104352>
- Chakrabortya, Anirban, Ahmed Ibrahim, Ana Maria Cruz (2018). A study of accident investigation methodologies applied to Natech events during the 2011 Great East Japan earthquake. *Journal of Loss Prevention in the Process Industries*, 51: 208-222.
- Cruz, A.M.* and Krausmann, E. (2013). Vulnerability of the Oil and Gas Sector to Climate Change and Extreme Weather Events. *Climate Change*, 121(1): 41-53.
- Cruz, Ana Maria*; and Suarez-Paba, MC (2019). Advances in Natech Research: An Overview. *Progress in Disaster Science*, 1: 100013. <http://dx.doi.org/10.1016/j.pdisas.2019.100013>
- Lam, C.Y., and Cruz, Ana Maria (2019). Risk analysis for consumer-level utility gas and liquefied petroleum gas incidents using probabilistic network modeling: A case study of gas incidents in Japan. *Reliability Engineering and System Safety*, 185 (May): 198-212.

Lam, C.Y.; K. Tai; and A.M. Cruz (2021). Topological network and GIS approach to modeling earthquake risk of infrastructure systems: A case study in Japan. *Applied Geography*, **127**: 102392. <https://doi.org/10.1016/j.apgeog.2021.102392>.

Luo, Xiaolong; Ana Maria Cruz*; Dimitrios Tzioutzios (2020). Extracting Natech Reports from Large Databases: Development of a Semi-Intelligent Natech Identification Framework. *International Journal of Disaster Risk Science*, **11** (6): 735-750. <https://doi.org/10.1007/s13753-020-00314-6>

Misuri, Alessio, Ana Maria Cruz*, Hyejeong Park, Emmanuel Garnier, Nobuhito Ohtsu, Akihiko Hokugo, Isamu Fujita, Shin-ichi Aoki, Valerio Cozzani (2021). Technological accidents caused by floods: the case of the Saga prefecture oil spill, Japan 2019. *International Journal of Disaster Risk Reduction* (under review).

OECD (2012). *Report of the workshop on Natech risk management*, Dresden, Germany, 23-25 May. No. 25.

OECD (2015). *Addendum. Guiding Principles for chemical accident prevention, preparedness and response (2nd Ed) to address natural hazards triggering technological accidents (Natechs)*. Series on Chemical Accidents No. 27.

Suarez-Paba, Maria Camila, and Ana Maria Cruz* (2021). A paradigm shift in Natech risk management: Development of a rating system framework for evaluating the performance of industry and enhancing territorial resilience. *Journal of Loss Prevention in the Process Industries* (under review).

Suarez-Paba, Maria Camila, Ana Maria Cruz*, and Felipe Muñoz (2020a) Emerging Natech risk management in Colombia: A survey of governmental organizations. *Safety Science*, **128**: 104777 <https://doi.org/10.1016/j.ssci.2020.104777>

Suarez-Paba, MC; Perreur, M.; Munoz, F.; and Cruz, Ana Maria* (2019) Systematic literature review and qualitative meta-analysis of Natech research in the past four decades. *Safety Science.*, **116**: 58-77.

Suarez-Paba, MC; Tzioutzios, D; Cruz, Ana Maria*; and Krausmann, E. (2020b) Towards Natech Resilient Industries. Chapter 5. In Yokomatsu, M & Hochrainer-Stigler, S (Eds). *Disaster Risk Reduction and Resilience*. Volume 1. Global Alliance of Disaster Research Institutes (GADRI) Book Series. Springer Nature.

Note: * Corresponding author

5. 主な発表論文等

〔雑誌論文〕 計7件（うち査読付論文 7件/うち国際共著 7件/うちオープンアクセス 1件）

1. 著者名 Lam C.Y., Tai K., Cruz A.M.	4. 巻 127
2. 論文標題 Topological network and GIS approach to modeling earthquake risk of infrastructure systems: A case study in Japan	5. 発行年 2021年
3. 雑誌名 Applied Geography	6. 最初と最後の頁 102392 ~ 102392
掲載論文のDOI (デジタルオブジェクト識別子) 10.1016/j.apgeog.2021.102392	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する
1. 著者名 Suarez-Paba, MC; Perreur, M.; Munoz, F.; and Cruz, AM	4. 巻 116
2. 論文標題 Systematic literature review and qualitative meta-analysis of Natech research in the past four decades.	5. 発行年 2019年
3. 雑誌名 Safety Science	6. 最初と最後の頁 58-77
掲載論文のDOI (デジタルオブジェクト識別子) 10.1016/j.ssci.2019.02.033	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する
1. 著者名 Cruz, AM; and Suarez-Paba, MC	4. 巻 1
2. 論文標題 Advances in Natech Research: An Overview.	5. 発行年 2019年
3. 雑誌名 Progress in Disaster Science	6. 最初と最後の頁 100013
掲載論文のDOI (デジタルオブジェクト識別子) 10.1016/j.pdisas.2019.100013	査読の有無 有
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1. 著者名 Suarez-Paba Maria Camila, Perreur Mathis, Munoz Felipe, Cruz Ana Maria*	4. 巻 116
2. 論文標題 Systematic literature review and qualitative meta-analysis of Natech research in the past four decades	5. 発行年 2019年
3. 雑誌名 Safety Science	6. 最初と最後の頁 58-77
掲載論文のDOI (デジタルオブジェクト識別子) 10.1016/j.ssci.2019.02.033	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1. 著者名 Lam, C.Y., and A.M. Cruz	4. 巻 185
2. 論文標題 Risk analysis for consumer-level utility gas and liquefied petroleum gas incidents using probabilistic network modeling: A case study of gas incidents in Japan.	5. 発行年 2019年
3. 雑誌名 Reliability Engineering and System Safety	6. 最初と最後の頁 198-212
掲載論文のDOI (デジタルオブジェクト識別子) 10.1016/j.res.2018.12.008	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1. 著者名 Chakrabortya, Anirban, Ahmed Ibrahima, Ana Maria Cruz	4. 巻 51
2. 論文標題 A study of accident investigation methodologies applied to Natech events during the 2011 Great East Japan earthquake.	5. 発行年 2018年
3. 雑誌名 Loss Prevention in the Process Industries	6. 最初と最後の頁 208-222
掲載論文のDOI (デジタルオブジェクト識別子) 10.1016/j.jlp.2018.01.003	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1. 著者名 Luo Xiaolong, Cruz Ana Maria, Tzioutzios Dimitrios	4. 巻 in press
2. 論文標題 Climate Change and Temporal-spatial Variation of Tropical Storm-related Natechs in the United States from 1990 to 2017: Is There a Link?	5. 発行年 2021年
3. 雑誌名 International Journal of Disaster Risk Reduction	6. 最初と最後の頁 102366 ~ 102366
掲載論文のDOI (デジタルオブジェクト識別子) 10.1016/j.ijdrr.2021.102366	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

〔学会発表〕 計12件（うち招待講演 8件 / うち国際学会 1件）

1. 発表者名 Cruz, A.M.
2. 発表標題 Disaster Management in Industry: The Case of Natechs.
3. 学会等名 Inter-American Development Bank; Kyoto University Roundtable for Disaster Risk Management. Seifu Kaikan, Kyoto University, Kyoto, Japan, 3 April, 2019. (招待講演)
4. 発表年 2019年

1 . 発表者名 Suarez-Paba, M.C. and Cruz, A.M.
2 . 発表標題 Natech risk management: the case of Colombia.
3 . 学会等名 Risk management and governance in the Anthropocene: An International Workshop on Natural Hazards Triggered Technological Risks (NATECH), Nanjing, China, 17-19 March 2019. (招待講演)
4 . 発表年 2019年

1 . 発表者名 Cruz, Ana Maria
2 . 発表標題 Overview of Natech research: Towards a resilience framework
3 . 学会等名 Risk management and governance in the Anthropocene: An International Workshop on Natechs, Nanjing, China (招待講演)
4 . 発表年 2019年

1 . 発表者名 Suarez-Paba, Maria Camila and Cruz, Ana Maria
2 . 発表標題 Natech risk management: The case of Colombia
3 . 学会等名 Risk management and governance in the Anthropocene: An International Workshop on Natechs, Nanjing, China (招待講演)
4 . 発表年 2019年

1 . 発表者名 Cruz, Ana Maria
2 . 発表標題 Natech Risk Communication: Moving Towards Comprehensive Risk Management
3 . 学会等名 IDRiM Conference, Sydney, Australia (国際学会)
4 . 発表年 2019年

1 . 発表者名 Suarez-Paba, Maria Camila and Cruz, Ana Maria
2 . 発表標題 Development of a screening methodology of natural hazard characterization and vulnerability assessment of exposed installations
3 . 学会等名 DPRI Annual Seminar, Kyoto, Japan
4 . 発表年 2019年

1 . 発表者名 Maekawa, Tomoki and Cruz, Ana Maria
2 . 発表標題 Simplified Modeling of an Oil Refinery Natech following the Great East Japan Earthquake Using Bayesian Network for Domino Effect
3 . 学会等名 UN/ OECD Workshop on Natech Risk Management (招待講演)
4 . 発表年 2018年

1 . 発表者名 Cruz, Ana Maria
2 . 発表標題 Risk Communication: Increasing Awareness for Better Disaster Preparedness
3 . 学会等名 UN/ OECD Workshop on Natech Risk Management (招待講演)
4 . 発表年 2018年

1 . 発表者名 Suarez-Paba, Maria Camila and Cruz, Ana Maria
2 . 発表標題 Natech Risk Management in Colombia: An overview based on a questionnaire survey
3 . 学会等名 UN/ OECD Workshop on Natech Risk Management (招待講演)
4 . 発表年 2018年

1. 発表者名 Suarez-Paba, Maria Camila and Cruz, Ana Maria
2. 発表標題 Systematic literature review of Natech risk management by natural hazard
3. 学会等名 Natech Symposium on "Natech Risk Reduction at Large Industrial Parks, Joint Research Center, European Commission, Italy (招待講演)
4. 発表年 2018年

1. 発表者名 Suarez-Paba, Maria Camila and Cruz, Ana Maria
2. 発表標題 Natech RateME: Comprehensive Natech Performance Rating System for Industrial Parks to Manage Risks from Extreme Events
3. 学会等名 Seminar Camp of Integrated Arts and Sciences for Disaster Reduction Research Group (Sogo Bosai Camp), Japan
4. 発表年 2018年

1. 発表者名 Ana Maria Cruz, Maria Camila Suarez-Paba
2. 発表標題 ccc
3. 学会等名 ttt
4. 発表年 2017年

〔図書〕 計1件

1. 著者名 Suarez-Paba, MC; Tzioutzios, D; Cruz, AM*; and Krausmann, E.	4. 発行年 2020年
2. 出版社 Springer Nature	5. 総ページ数 340
3. 書名 Towards Natech Resilient Industries. Yokomatsu, Muneta, Hochrainer-Stigler, Stefan, GADRI Book Series.	

〔産業財産権〕

〔その他〕

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6. 研究組織

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連携研究者	多々納 裕一 (Tatano Hirokazu) (20207038)	京都大学・防災研究所・教授 (14301)	

7. 科研費を使用して開催した国際研究集会

〔国際研究集会〕 計4件

国際研究集会 5th International Symposium on Natural and Technological Accident Risk Reduction at Large Industrial Parks, Osaka, Japan	開催年 2021年～2021年
国際研究集会 Taller internacional sobre riesgos Natech, Area Metropolitana del Valle de Aburra, Medellin, Colombia	開催年 2019年～2019年
国際研究集会 4th Natech Symposium, Joint Research Centre, European Commission, Ispra, Italy	開催年 2018年～2018年
国際研究集会 3rd Natech Symposium and Workshop, Osaka, Japan	開催年 2017年～2017年

8. 本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関