PAIRS – Privacy-aware, intelligent and resilient crisis management

Sabine Janzen[1,*], Agbodzea P. Ahiagble[1], Lotfy Abdel Khaliq[1], Natalie Gdanitz[1], Prajvi Saxena[1], Prathvish Mithare[1], Denys Skrytskyi[1] and Wolfgang Maass[1,2]

[1]*Deutsches Forschungszentrum für Künstliche Intelligenz (DFKI), Saarbruecken, Germany*
[2]*Saarland University (UdS), Saarbrücken, Germany*

Abstract

In an era characterized by unpredictability and increasingly interconnected systems, crisis management becomes a formidable challenge. This paper introduces the PAIRS project (06/2021 - 05/2024), an ongoing research initiative funded by the German Federal Ministry of Economics and Climate Protection, aiming to enhance crisis management through AI-based smart crisis management services. Building on artificial intelligence (AI) and large-scale data, PAIRS empowers a shift from reactive to proactive crisis management in organizations spanning multiple sectors, including civil protection, healthcare, production & supply chains, and energy. The PAIRS consortium, a multidisciplinary collaboration of eleven industry and academic partners, explores the use of smart crisis management services to effectively manage the complexity and scale of modern crises, ensuring fast recovery and improved resilience. This paper provides a comprehensive overview of the PAIRS project, outlining its objectives, work packages, and anticipated outcomes. A central focus is the role of conceptual modeling from both process and product perspectives within PAIRS, with specific emphasis on the current state of work in modeling crisis scenarios across various domains.

Keywords

Crisis management, Artificial Intelligence, Resilience, Smart Crisis Management Services, Conceptual modeling, Crisis scenarios, Knowledge graph

1. Introduction

In an increasingly interconnected and dynamic world, crises are inevitable, hard to predict, and pose immense challenges that demand robust, effective and timely management. Over the last decade, various types of crises have impacted societies, economies, and environments globally [1]. For instance, the COVID-19 pandemic in 2019 unleashed a global health crisis with sweeping socio-economic consequences [2, 3, 4]. Further, in 2020, the wildfires that devastated Australia and California underlined the urgency of dealing with climate crises [5]. Meanwhile, the 2021 Suez Canal obstruction demonstrated the vulnerability of global supply chains [6].

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*Corresponding author.
sabine.janzen@dfki.de (S. Janzen); agbodzea_pascal.ahiagble@dfki.de (A. P. Ahiagble); lotfy.abdel_khaliq@dfki.de (L. A. Khaliq); natalie.gdanitz@dfki.de (N. Gdanitz); prajvi.saxena@dfki.de (P. Saxena); prathvish.mithare@dfki.de (P. Mithare); denys.skrytskyi@dfki.de (D. Skrytskyi); wolfgang.maass@dfki.de (W. Maass)

While these crises differ in their nature and scale, they all require rapid response and effective management. Traditional methods, often plagued by human bias and slow response times, can fall short of successfully managing these crises. Artificial Intelligence (AI) has created new opportunities to improve crisis management leveraging machine learning, predictive analytics, and natural language processing, among other technologies, to collect, analyze, and interpret vast amounts of data in real-time [7]. This enables the identification of emerging crises, the prediction of their potential impacts, the creation of response strategies, and the implementation of those strategies in a timely and effective manner.

PAIRS is an ongoing research project funded by the German Federal Ministry of Economics and Climate Protection (06/2021 - 05/2024) that investigates **privacy-aware, intelligent and resilient crisis management**[1]. By means of AI and data-driven smart crisis management services (SCMS), companies, government and health organizations as well as civil protection are enabled to move from a reactive stance to a more proactive one, anticipating crises and mitigating their impacts. The project consortium consists of eleven partners from industry and academia that take different roles in the project: industry end users (Sick, Bisping), civil protection end users (THW), system providers (Advaneo, Tiplu, IBM), and research & development (DFKI, Fraunhofer IPA, FIR at RWTH Aachen, Saarland University, OFFIS). PAIRS investigates the application of AI-based SCMS in the domains of civil protection, production & supply chains, healthcare, and energy with the objective to handle the complexity and scale of contemporary crises, ensuring quicker recovery and better resilience.

In this paper, we present an overview of the PAIRS project, including its objectives, work packages and expected outcomes. We will discuss the role of conceptual modeling in PAIRS from a process and product perspective, especially focusing on the current state of work in modeling crisis scenarios in diverse domains.

2. Project objectives

PAIRS aims to develop a cross-domain platform for crisis management to identify and anticipate crisis scenarios on the basis of a hybrid AI approach. In doing so, the availability of essential resources and capabilities of enterprise ecosystems shall be secured, and their marketability sustainably strengthened. In particular, the interactions between economic and political actors will be considered, taking into account data sovereignty and data privacy. The risks of individual crisis scenarios (concrete manifestations of the crisis event together with the general reactions) are assessed on an actor-specific basis. Based on the risk assessment and a self-expanding pool of measures, individual response measures are derived for individual crisis scenarios, which are fed back (pseudo-)anonymized into a crisis scenario generator. The resulting iterative precision of the crisis scenarios, together with the continuous adaptation of all response measures, contributes to a well-founded information basis in order to be prepared in the best possible way for potential crisis situations. The project's work packages have been distributed among the partners based on their respective areas of expertise. As depicted in Figure 1, the project is structured into ten sub-projects, each labeled as a work package (WP). WP1, led by FIR at RWTH Aachen, aims to define, structure, and prioritize crisis management use cases using a

[1]https://www.dfki.de/en/web/research/projects-and-publications/project/pairs

knowledge base. WP2 is led by ADVANEO and focuses on investigating and consolidating existing reference architectures while mapping general requirements. ADVANEO also leads WP3, tasked with developing data integration strategies for PAIRS-compliant connection of services and data governance. WP4, under the leadership of DFKI, involves analyzing existing research approaches, AI algorithms, modules, frameworks, and tools for core technical topics. Saarland University takes charge of WP5, which involves evaluating the feasibility of extensive data anonymization for AI tools in PAIRS from functional and legal perspectives. Fraunhofer IPA leads WP6, responsible for researching and identifying relevant resilience approaches for stable production and supply chains in crisis situations, as well as seizing business opportunities. WP7, led by FIR, focuses on the conceptual design of the procedure for acceptance and benefit validation. ADVANEO also leads WP8, responsible for the conceptual design of acceptance and benefit validation procedures, integration of partners' exploitation paths, and defining economic goals. Finally, Saarland University leads WP9, which focuses on creating an ecosystem for project exploitation during and beyond the project.

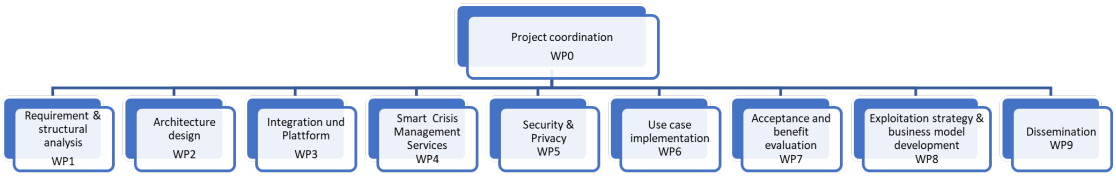

Figure 1: List of the work packages in PAIRS project (Source: PAIRS project).

3. Conceptual modeling for smart crisis management services (SCMS)

Conceptual modeling has a pivotal role in PAIRS, bridging theoretical constructs with practical AI-based solutions for crisis management and was applied from a product and process perspective within the project. In this section, we demonstrate the role of conceptual modeling within work package 4 (WP4), i.e., process perspective, as well as regarding first results with respect to use cases and services, i.e., product perspective.

3.1. Work package 4: Process perspective

The goal of WP4 is the conceptual and technical specification as well as prototypical implementation of specific and generic AI modules for SCMS in iterative proof-of-concept (PoC) cycles. In the foundational phase, a comprehensive state analysis was conducted to review the current research strategies, AI algorithms, AI modules offered by system providers, and relevant tools and frameworks. Following this, relevant data sets were identified, acquired, and processed. Next, implementation strategies for core technical subjects such as explainable and responsible AI, AI-based crisis communication and episodic crisis scenario knowledge graphs were developed. Followed by technical specifications of the required AI modules, AI models were designed, trained and integrated into modules for the PAIRS platform. Last, benchmarking of the performance of these modules is done in an evaluation phase. In order to optimally address the challenging technical issues in WP4, DFKI, as WP leader, developed a proposal for combining the horizontally designed work packages with a vertical agile logic. For this purpose, the SCRUM approach is adapted to research projects following the SCORE method [8]. Five sprint categories are distinguished: Knowledge Transfer, Research, Conceptual Modelling, Implementation, and Publication, as shown in Figure 2. Each project month is organized as a sprint of one category. At the beginning of each month, a sprint jour fixe (JF) takes place in WP4, where the last sprint is reviewed and the next sprint is planned. In each Knowledge

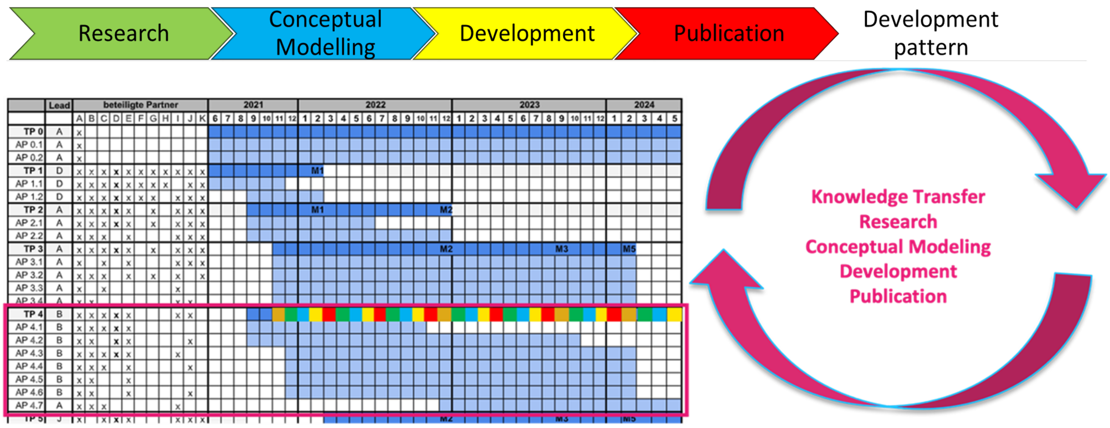

Figure 2: Sprint categories and work planning in PAIRS work package 4 (TP4) according to SCORE method.

Transfer sprint, the team determines essential knowledge that needs to be shared for effective collaboration. Knowledge Transfer sprints take place in project months 6, 19, 28 and 33 (matching the milestones of PAIRS). Research sprints cover knowledge engineering work, i.e., research and analysis of existing work, approaches, algorithms, tools, etc. Conceptual Modelling sprints aim at the development of new solution concepts and the specification of conceptual models for these solutions informed by earlier sprint outcomes. Implementation sprints focus on the technical realization of pre-defined concepts, starting with the alignment of user stories for the upcoming PoC or prototype. This sprint might also include evaluations or studies beyond pure technical developments. Publication sprints induce the objective of converting findings of the previous sprint into results, i.e., writing scientific publications, (technical) report, white paper, state of the arts, etc. Planning and executing the sprints in WP4 are aligned with the overall project goals by the work package lead (”Are the intended results of the current sprint aligned with the WP and project goals?”). Furthermore, sprints are documented in condensed form (sprint plan, user stories, sprint results, review). Five sprint cycles were completed in the project until September 2023. An overview of the AI modules that are planned, in progress or completed and thus available can be found in Figure 3.

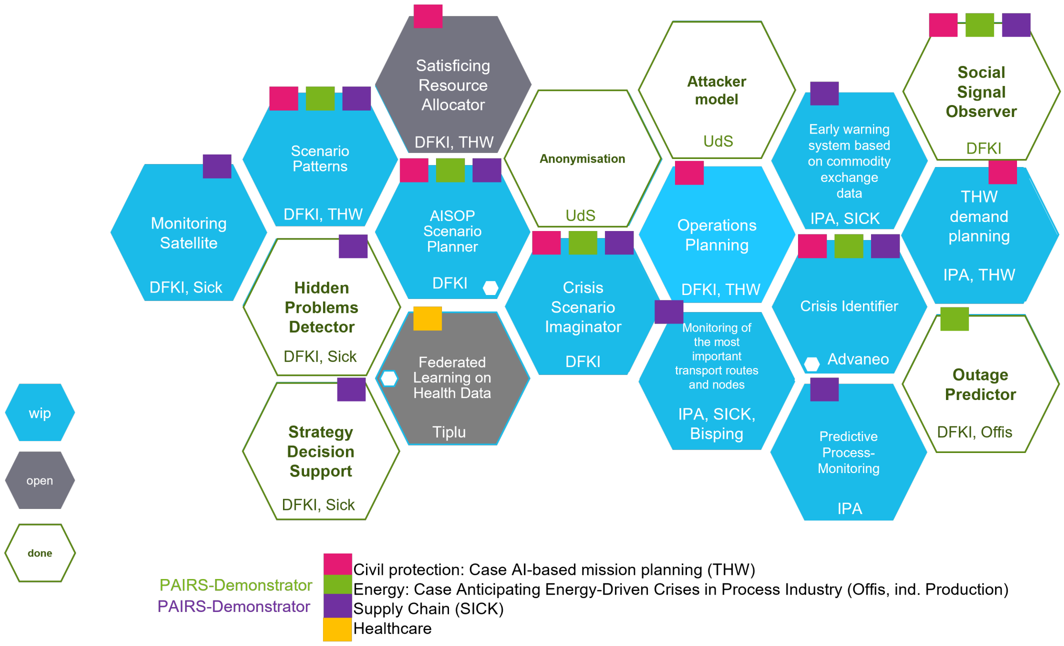

Figure 3: Overview of AI modules that are work-in-progress (wip), planned (open) or done in PAIRS work package 4: Smart Crisis Management Services (SCMS) (09/2023). Modules have titles and involved respective responsible partners in PAIRS. Modules can be applied in single or multiple use cases defined in PAIRS: civil protection, energy, supply chain and production as well as healthcare. After integration of modules in use case-specific SCMS prototypes are available that can be used as PAIRS demonstrators.

3.2. AI modules and use cases: Product perspective

In PAIRS WP4, several modules were developed and evolved to use case-specific service implementations (product perspective) (cf. Figure 3). Resulting services were showcased within publications, demonstrators, one pagers and screencasts. An extract of finalized modules will be highlighted in this section.

Outage predictor - Prediction of regional power outages for industrial production: Power outages and fluctuations represent serious crisis situations in energy-intensive process industries (e.g., glass and paper production), where substances such as oil, gas, wood fibers or chemicals are processed. Power disruptions can interrupt chemical reactions and produce tons of waste as well as damage of machine parts [9, 10, 11]. But, despite of the obvious criticality, handling of outages in manufacturing focuses on commissioning of expensive proprietary power plants to protect against power outages and implicit gut feeling in anticipating potential disruptions [9]. Within this use case, three modules (i.e., AI-based scenario planning (AISOP), scenario patterns, outage predictor) were aggregated to a service prototype (Python, JSON-LD, Neo4j, Django, HTML, JS) for predicting energy-driven disruptions (cf. Figure 3). We introduced AISOP (cf. Figure 4) as a model for AI-based scenario

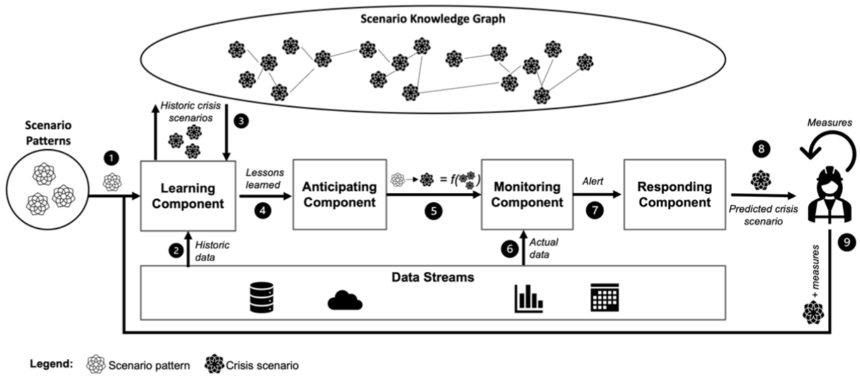

Figure 4: AI-based scenario planning for predicting crisis situations: AISOP module.

planning for predicting crisis situations that uses conceptual, well-defined scenario patterns (JSON-LD) to capture entities of crisis situations within an scenario knowledge graph that can be used to predicting future crisis scenarios by predictive analytics [9]. The model was exemplified within an outage predictor service[2] that enables the prediction of regional power outages for locations of the German paper industry for max. 7 days (accuracy: 0.81, sensitivity: 0.70)[12][3].

Hidden problem detector - Identification of hidden problems in supply chains: Component-based supply chains of products are increasingly non-transparent beyond tier 1 suppliers [13, 14]. Disruptions in early stages remain undetected, propagate, and reinforce before popping up as critical situations at tier 1 [15, 16, 17]. Despite criticality, traditional supply chain management focuses on reactive measures at tier 1 or 2 for these hidden problems [18]. In PAIRS GRASPER was developed (cf. Figure 5), a model for graph-theoretical analysis of component criticality that uses multiple centrality measures to detect hidden problems in component-based supply chains [17]. Bill-of-Materials (BOM) data are automatically

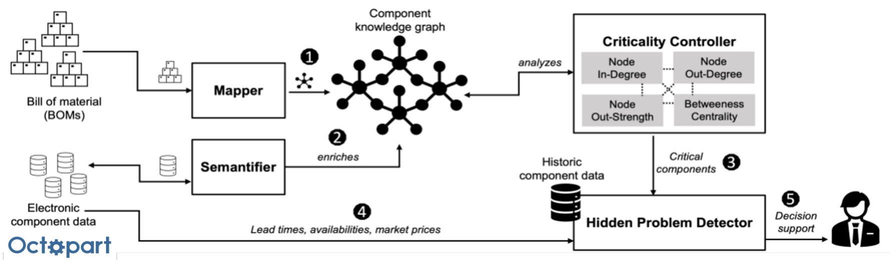

Figure 5: Model for graph-theoretic analysis of component criticality in supply chains: Hidden problem detector module.

[2]https://github.com/InformationServiceSystems/pairs-project/tree/main/Modules/OutagePredictor
[3]https://www.youtube.com/watch?v=pj6K4pOvoDs&t=18s

mapped onto a knowledge graph, semantically enriched, and fed with historical and actual market data (e.g., availabilities, prices) provided by Octopart [4][17]. The Criticality Controller performs graph-theoretic analysis with respect to in-degree, out-degree, out-strength, and betweenness-centrality of nodes to determine the criticality of supply chains on a component level. The model is applied in the Hidden Problem Detector (Flask, Python, Neo4j, Octopart)[5] for hidden problem detection in sensor manufacturing supply chains (cf. Figure 3) [17][6].

Social signal observer - Social signal detection for crisis prediction: Crises emit weak early warning signals, difficult to detect amid daily noise [19, 20, 21]. Signal detection mechanisms in crisis management aim for early identification and proactive organizational responses [22, 23, 24, 25]. Observation of social signals in information sources (e.g., social media) enables early identification of crises supporting proactive organizational responses before a crisis occurs. In PAIRS, we introduced an AI model to support open-domain signal detection of crisis-related indicators in Twitter posts that was instantiated in a service Social Signal Observer (Python, Flask, HTML, CSS, Javascript) (cf. Figure 3) [21][7]. Here, we work

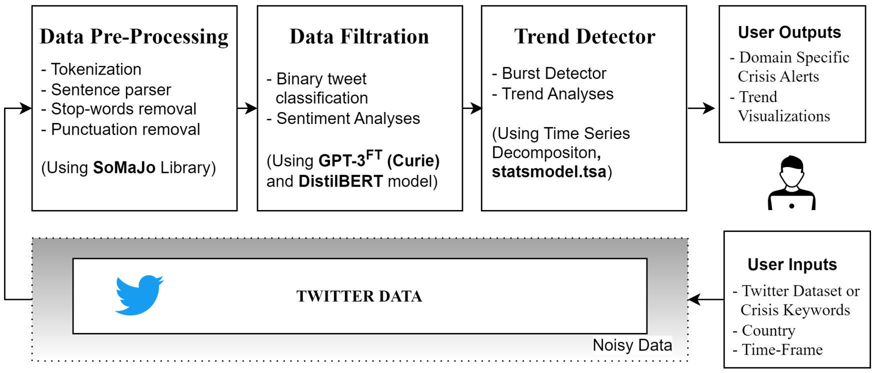

Figure 6: Model for open-domain social signal detection of crisis-related indicators in tweets: Social signal observer.

with multi-lingual Twitter data and combine multiple state-of-the-art models such as, GPT-3, RoBERTa [8], and STANZA [26]. The service accepts inserted keywords by the user regarding crisis signals of interest along with a selection of country, language and time frame as input. For detected domain-specific signals, alerts with confidence and severity are triggered and presented.

[4]https://octopart.com/
[5]https://github.com/InformationServiceSystems/pairs-project/tree/main/Modules/HDP
[6]https://www.youtube.com/watch?v=Xixp7x7hhQU&t=24s
[7]https://github.com/InformationServiceSystems/pairs-project/tree/main/Modules/OSOS
[8]https://huggingface.co/joeddav/xlm-roberta-large-xnli

4. Conclusion and future work

Facing an ever-evolving global landscape marked by multifaceted crises, the need for advanced, agile, and efficient crisis management tools has never been more pronounced. The PAIRS project, as delineated in this paper, investigates the potential of harnessing AI and data-driven methods for transforming the way we approach, understand, and mitigate crises. By integrating privacy-aware, intelligent, and resilient strategies, PAIRS not only addresses the immediate challenges of crisis management but also anticipates future threats, ensuring a proactive stance. Accompanied by the collaborative and diverse nature of the project consortium consisting of industrial and academic partners, conceptual modeling plays a crucial role in PAIRS, both from a process and product perspective, for enabling a structured, low-threshold and result-driven approach to AI-based crisis management. This ensures that the solutions developed are both adaptable to diverse domains and scalable to the magnitude of contemporary crises. There are several avenues for future work including the technical and empirical evaluation of the modules including studies with decision makers. In conclusion, PAIRS offers a promising glimpse into the future of crisis management. By leveraging the power of AI, it seeks to transform reactive responses into proactive strategies to be more resilient by means of smart crisis management services.

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