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Artificial Intelligence Metamodel for Controlling and Structuring the Crisis Management Domain

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Abstract: Crisis management is the process through which a company deals with a significant and unpredictable incident threatening the company and its stakeholders. It aims to reduce the risk or impact of a crisis event and ensure the organization can continue to operate and prosper in the aftermath of the event. Various studies have been conducted on how to best manage and control the crisis management domain. However, the literature still lacks a descriptive metamodel applicable to solving the problems the domain practitioners may face. Therefore, this study adopted an Artificial Intelligence (AI) concept to control, structure, and manage the crisis management domain, based on design science research. The developed AI metamodel consists of 14 common concepts that can assist the domain practitioners to structure and manage the crisis management domain. Furthermore, the trancing technique was used to verify the effectiveness and applicability of the developed metamodel to the real-world problems of crisis management. The AI metamodel developed in this study can assist domain users in addressing crisis events and improvising decision-making processes. It incorporates real-time data from various sources to provide situational awareness for decision-makers and identifies relevant tactical plans to address crises.

Keywords: Artificial Intelligence, Crisis Management, Metamodel, Metamodeling, Design Science Research

Introduction

Crisis management refers to the process of dealing with a disruptive and unexpected event that threatens an organization, its stakeholders, or the general public (Gichuhi *et al*., 2023). The study of crisis management originated in the middle of the large-scale industrial and environmental disasters that occurred in the 1980s. It is the most important function in public management as it involves strategies and tactics to prevent, mitigate and recover from crises.

Artificial Intelligence (AI), which is used to achieve the objectives of this study, is a method of making computers, robots, or software think intelligently: The way human beings think (Leachu *et al*., 2022). By studying the way people think, learn, decide, and work and then applying the findings of these studies to the development of intelligent software and systems, AI is accomplished.

Metamodels essentially describe 'concepts' and the relationships between the concepts allow to-be-defined models to conform to the metamodel (Benaben *et al*., 2020). As far as knowledge management goes, metamodels are also frequently used to describe the high-level structure of an ontology within this domain (Al-Dhaqm *et al*., 2014). It is a common practice to use abstract concepts (and their relationships) as a means of describing the ontology that can be instantiated when populating the schema with data. Metamodels play a particular role in the domain of model transformation, where the concept is used frequently and plays a highly significant role (AL-Dhaqm, 2019).

Thus, this study is aimed at developing a metamodel that can control and structure the crisis management domain by means of AI. Crisis management can be summed up as a set of concepts that can effectively be used to plan, manage and monitor the response to a crisis. The results of this study have several contributions; the two most important are 1) providing the opportunity to examine various components and aspects of crisis management through data-driven analysis, which facilitates the decision-making process in this area and 2) providing decision-makers with a simple and easy-to-access source of information regarding crises and the way they develop.

AI provides numerous aids in organizing and controlling crisis management; for example, it can process

massive volumes of data in real time, allowing quicker and more precise investigation of crisis situations. This aids in classifying designs, trends, and differences, which eases knowledgeable decision-making. In addition, AI algorithms examine old data, classify possible crisis situations and then propose events to be taken. Analytics can aid in the initial discovery of crises, minimalize their influence and improve response time. Additionally, AI can mix data from many sources, e.g., social media, sensors, news feeds, and surveillance systems, offering a complete and real-time image of the crisis condition. This recovers situational awareness and aids in making opportune and targeted responses.

Related Work

To control and structure crisis management, different models, frameworks, methods, and tools have been proposed over the years. For example, the authors of Lauras and Comes (2015) suggested an intelligent decision-support system for crisis management using Non-Axiomatic Logic. They proposed a framework that can be used to develop concrete reasoning capabilities. This framework allows for reasoning and learning mechanisms to be used in urban firefighting applications. The system is designed to be able to receive and process data from both human and machine sources and then use this data to generate a list of possible solutions to the crisis. The system then uses Non-Axiomatic Logic to reason through various solutions and determine the best course of action. The system also considers any changes to the environment, which might affect the outcome, allowing for more dynamic and adaptive decision-making. Bennani *et al*. (2017), the authors developed a model called COLIBRI to prevent terrorist attacks. To support decision-making, their preventive model is designed to obtain and reuse information about prior attacks previously resolved successfully. It is beneficial to fully understand each situation, especially when it involves a terrorist attack and to construct alternative solutions aligned with preventive and/or corrective measures. It consists of two major components: A Case-Based Reasoning (CBR) process and knowledge models that are described by an ontology. The authors Wrzalik and Jereb (2019) proposed a model to use an expert system to support the decision-making process in banks. An expert system is a computer system designed to emulate the decision-making ability of a human expert. The system uses a set of rules and data to provide advice or recommendations on a variety of topics such as banking and finance. This model can help banks to make informed decisions and reduce the risk of making mistakes. In Bénaben *et al*. (2008), the authors discussed the French Interoperability of Systems in Crisis Situations (ISyCri) project with the aim of providing a Mediation Information System (MIS) for all partners involved in crisis management. In another study Han and Xu (2015), the authors introduced a novel information-fusion-based emergency management decision support system that is ontology oriented. Initially, an emergency ontology is developed for data and model integration, which is then followed by a five-layer framework-based decision support system that is specifically developed to facilitate emergency management. Therefore, multi-source data are integrated as inputs and outputs to pre-process the data for decision-making accordingly. Kruchten *et al*. (2008), authors presented an ontology of disasters affecting critical infrastructures. They included people in the process and made a distinction between the physical and social interdependencies between infrastructures, based on the social layer dealing with coordination and communication among the representatives of various critical infrastructures (which may be people or intelligent agents). The authors Elmhadhbi *et al*. (2019) defined the complex knowledge of ERs (Emergency Responders) by proposing a common and modular ontology shared by all stakeholders to compose a commonly shared vocabulary and ensure semantic interoperability between ERs. In Benaben *et al*. (2019), a model-based AI framework was developed to describe collaborative scenarios, along with a formal metamodel intended to be instantiated based on the scenarios across a variety of application domains. The partners (the involved organizations as well as their capabilities, relations, and resources), the context (the social, physical, and geographical environment), and the objectives help compensate this metamodel that describes collaborative situations between organizations. In Antunes *et al*. (2013), the authors provided systems and databases with the most comprehensive representations of machine-interpretable semantics. They supported semantic interoperability between heterogeneous systems by acting as both knowledge representation and mediation. In another study Casado *et al*. (2015), the authors proposed a disaster project, called EMERGEL, where ontology was primarily focused on mapping various predefined information artifacts, information representation, and language between European countries. It consists of a vertical module (organization's specifications), a transversal module (time and space), and a core ontology (events and agents). Fan and Zlatanova (2011), the authors proposed an ontology as an attempt to address the issue of spatial data heterogeneity in emergency situations and its dissemination to stakeholders. In Khalifa *et al*. (2022), a comprehensive analysis was conducted on the positive and negative impacts of AI on HR crisis management. The authors discussed how AI can help organizations manage their workforce in times of crisis, such as the case of the COVID-19 pandemic,

by automating decision-making processes, identifying key performance indicators, predicting potential problems, and optimizing HR resources. In Farrokhi *et al*. (2020), the authors offered a fundamental approach comprised of a numerical and emotional big data analytics method. In another research Ali and Wood-Harper (2022), a review study was conducted on crisis management and existing categorizations before delving into crisis decision-making. The literature review covered different aspects of crises such as the cognitive, emotional, and social components of decision-making in a crisis, as well as the role of risk-taking in crisis decision-making. An AI-based decision-making framework was designed by Essien and Petrounias (2022) to help decision-makers make better, more informed decisions during crises. A comprehensive overview was provided by AI technology and data-driven insights. A plan of action could then be developed and the progress of the effort could be tracked. The authors Essien and Petrounias (2022) demonstrated how to optimize lean maintenance procedures and maximize efficiency by implementing intelligent systems. Using AI-based systems, they analyzed data, monitored performance, detected anomalies, and even suggested improvements to processes. A landmark study was carried out by the team of streamflow and flooding experts in Mughal *et al*. (2021), which discussed the challenges associated with constructing a large-scale spatiotemporal tracking system for managing streamflow and flooding in watersheds. To address some of these challenges, they proposed an ontological semantic model consisting of an ontology of spatiotemporal concepts and a semantic knowledge base, both of which are based on a formal ontology of spatiotemporal concepts.

As well as this, a number of digital forensic works have been proposed to be applied to the detection and investigation of risks and threats to organizations. As a result of the use of digital forensics in organizations, security incidents can be identified and handled more effectively. Digital forensics is also beneficial in terms of mitigating risks, enhancing a company's overall security posture, and reducing vulnerabilities. The authors of the article have proposed and developed several models, frameworks, and methodologies for analysing and interpreting the data in Al-Dhaqm (2019); Al-Dhaqm *et al*. (2014; 2015; 2018; 2021a-b; 2023a-b); Alotaibi *et al*. (2022a-b); Ghabban *et al*. (2021); Ameerbakhsh *et al*. (2021); Alhussan *et al*. (2022a-b); Yafooz *et al*. (2023); Alfadli *et al*. (2021); Abd Razak *et al*. (2016; 2020); Salem *et al*. (2023); Saleh *et al*. (2021; 2023; Ali *et al*. (2015; 2018; 2021); Baras *et al*. (2021); Zawali *et al*. (2021) to investigate and detect cybercrime, data breaches and other digital threats to organizations.

Based on existing literature reviews, the authors of the current paper were able to uncover several ontologies, frameworks, metamodels, and models that were established in the context of crisis management based on their analysis of existing literature. However, the ontologies, frameworks, and models already proposed in the literature lack knowledge of various concepts involved in the crisis management domain. It is therefore the objective of this study to develop an AI metamodel using a metamodeling approach with the aim of controlling and structuring the crisis management domain.

Materials and Methods Development Process

This research was conducted in conjunction with Design Science Research (DSR), which was used to develop an AI metamodel for managing and controlling crises in professional environments. DSR is typically referred to as an approach to solving practical problems using scientific principles (Peffers *et al*., 2007). As part of this study, we adapt the metamodeling approach to develop an AI metamodel capable of controlling and structuring crisis management. Metamodeling is used to build abstract models that represent information about environmental conditions and characteristics of a given system. Figure 1 displays the metamodeling design in Model Driven Architecture (MDA). MDA is a methodology for developing software applications in which models and model-based tools are used in the software application creation process (Atkinson and Kuhne, 2003). It is based on the concept of separating the business logic of a software application from its implementation details, making it easier to customize and adapt the application based on different environments.

Figure 2 displays the steps taken in the current study to develop an AI metamodel for controlling and structuring the crisis management domain.

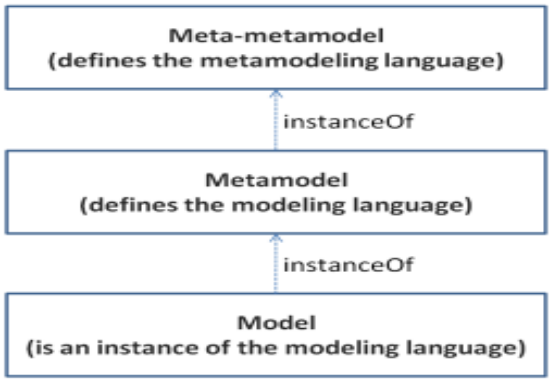

Fig. 1: Metamodeling design in MDA (Cetinkaya and Verbraeck, 2011)

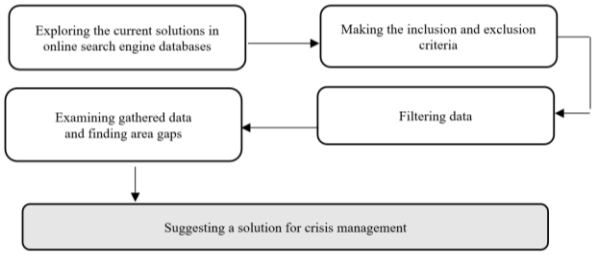

Fig. 2: Steps involved in the development methodology

Table 1: Summary of gathered articles from the search engines

Search engines	Discovered articles
Web of science	60
Scopus	35
IEEE explorer	23
Google scholar	122
Springer	200

Exploring the Current Solutions in Online Search Engine Databases

Several solutions have been already proposed in the literature for managing and controlling the crisis management domain. Particularly, the current online search engine databases offer a variety of solutions for managing the crisis management domain. These solutions range from pre-built AI metamodels to custom-made ones. The most popular online search engine databases for exploring the current solutions include Web of Science, Scopus, Springer, IEEE Explorer, and Google Scholar. Table 1 lists the solutions discovered for the crisis management domain using keywords such as "metamodel"; "ontology"; "AI"; and “Crisis Management”. A total of 440 articles were discovered in this search.

Making the Inclusion and Exclusion Criteria

The study adhered to the following set of criteria:

i. Inclusion criteria:

a) Studies published in relevant, peer-reviewed journals
b) Studies conducted during the last five years
c) Studies discussing AI models specifically designed for crisis management
d) Studies providing evidence of the success or failure of AI models for crisis management
e) Studies including detailed descriptions of the data and AI models used

ii. Exclusion criteria:

a) Studies not published in relevant, peer-reviewed journals
b) Studies conducted more than five years ago
c) Studies focusing on general AI models and not specifically designed for crisis management
d) Studies providing only theoretical insights without any empirical evidence
e) Studies lacking detailed descriptions of the data and AI models used

Filtering Data

Data from the common search engines were filtered according to the inclusion and exclusion criteria listed above, which resulted in the selection of only 50 out of 440 studies.

Examining Gathered Data and Finding Area Gaps

The gathered data can be used to identify area gaps in the crisis management domain by analyzing the data and identifying any potential weaknesses or deficiencies in the current crisis management domain. This analysis can be used to identify any vulnerabilities or areas where improvements are needed, as well as any areas that may require any additional resources or strategies. For example, upon analyzing the data for controlling and managing crisis management, it was recommended that crisis management needs highly abstract metamodels to structure, manage and organize the crisis management domain.

Suggesting a Solution for Crisis Management

The study suggests that a metamodel for crisis management should be developed and validated using AI. Figure 3 displays the developed AI metamodel built based on gathering common concepts of the AI models for crisis management. Figure 3 includes the 14 common concepts presented in Table 2.

Implementation of Developed AI Metamodel

In this section, the established metamodel will be evaluated using the tracing technique. It is identified as the most commonly used metamodeling method to assess the efficiency of the established AI metamodel Ali *et al*. (2021). This technique includes making a map of the metamodel concepts and their associated relationships (Ali *et al*., 2021). Generally, it includes investigating the metamodel's construction, performance, and possessions and classifying associations between them. This is shown to clarify the system's overall building, its mechanisms, and its connections. Furthermore, it aids in classifying the possible flaws in the metamodel and parts for development. Figure 4 shows the tracing techniques for the established metamodel. For example, the <<*Controlling Crisis*>> concept in the metamodel can be used to instantiate numerous concepts to design a user model as shown in Fig. 4. Therefore, six explicit concepts have been instantiated from the high abstract concepts based on the tracing technique; the concepts are <<Develop a Crisis Management Plan>>, <<Identify and Monitor Potential Risks>>, << Develop Policies and Procedures>>, <<Establish a Crisis Communication Plan>>, <<Build a Response Team>> and <<Create a Crisis Management Process>>.

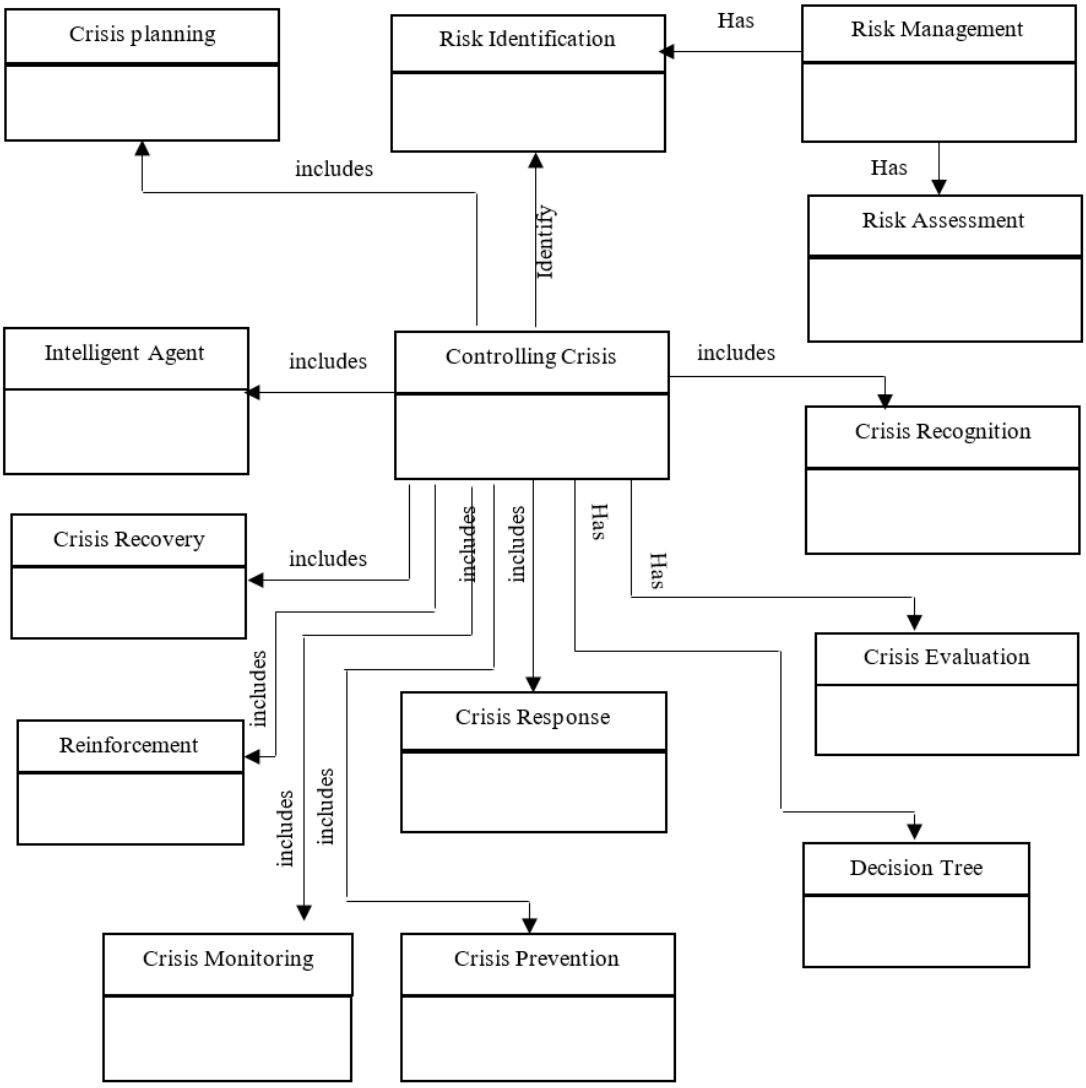

Fig. 3: AI metamodel for managing and controlling crisis management

Table 2: The proposed common concepts and their relationships for the AI models for the crisis management

Proposed common concepts	Relationships with another concept
Controlling crisis	Risk assessment (☑), Risk management (☑), Intelligent agent (☑), Decision tree (☑), Reinforcement learning (☑), Crisis recognition (☑), Crisis monitoring (☑), Crisis evaluation (☑), Risk identification (☑), Crisis planning (☑), Crisis response (☑), Crisis recovery (☑)
Risk assessment	Risk management (☑)
Risk management	Risk identification (☑)
Intelligent agent	Controlling crisis (☑)
Decision tree	Controlling crisis (☑)
Reinforcement learning	Controlling crisis (☑)
Crisis recognition	Controlling crisis (☑)
Crisis monitoring	Controlling crisis (☑)
Crisis evaluation	Controlling crisis (☑)
Risk identification	Controlling crisis (☑)
Crisis planning	Controlling crisis (☑)
Crisis response	Controlling crisis (☑)
Crisis recovery	Controlling crisis (☑)
Crisis prevention	Controlling crisis (☑)

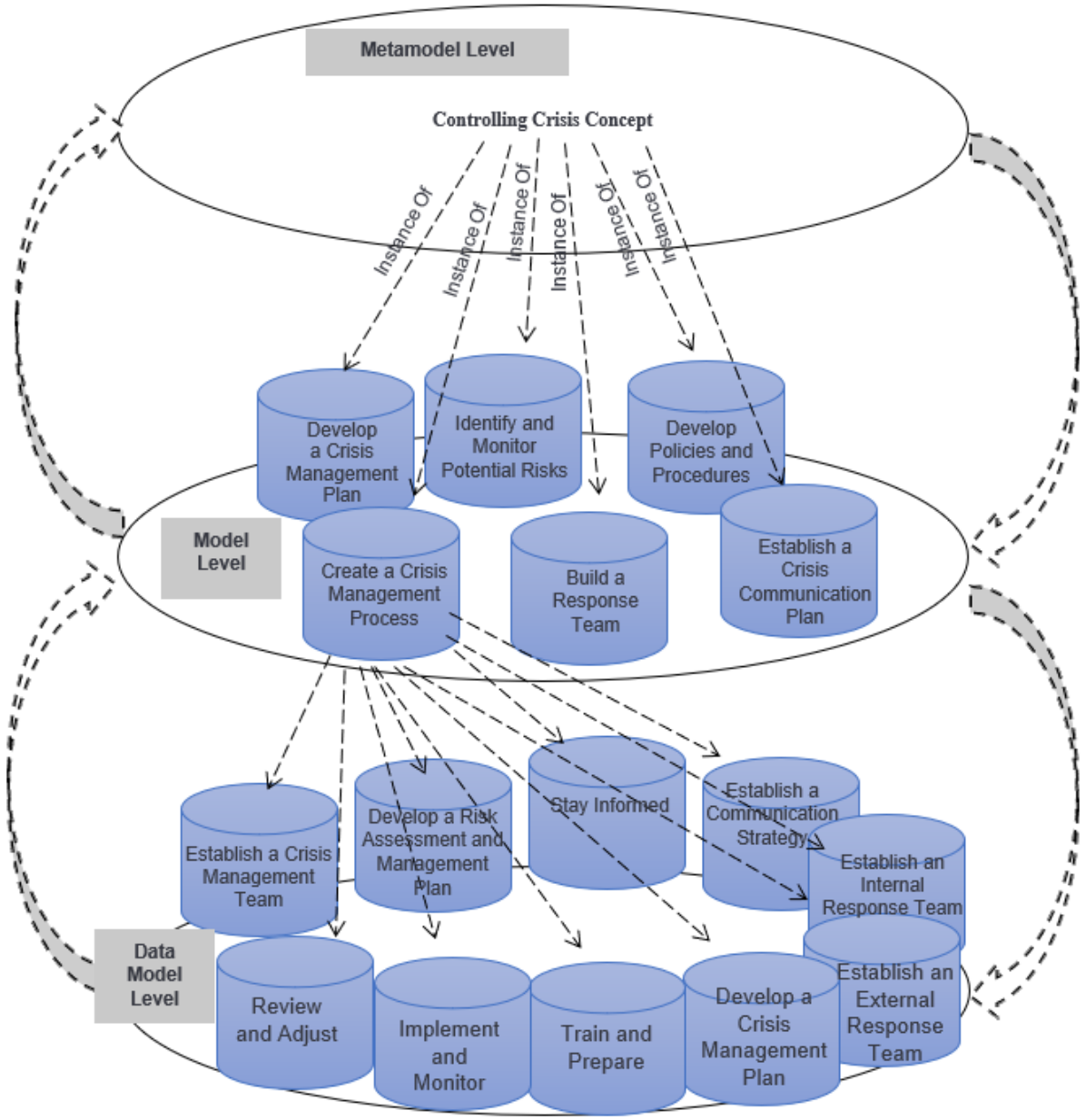

Fig. 4: Derive a solution model from the developed metamodel

These six concepts are combined in the user model, which is called the controlling crisis model. It allows users to derive several specific solution models as illustrated in Fig. 4. For example, <<*Create a Crisis Management Process*>> allows users to instantiate several specific concepts used to build the user data model, e.g., <<Establish a Crisis Management Team>>, <<Develop a Risk Assessment and Management Plan>>, <<Stay Informed>>, <<Establish a Communication Strategy>>, <<Establish an Internal Response Team>>, <<Establish an External Response Team>>, <<Develop a Crisis Management Plan>>, <<Train and Prepare>>, <<Implement and Monitor>> and <<Review and Adjust>>.

Results and Discussion

Briefly, this study aimed to develop an AI metamodel for managing and controlling crisis situations. Accordingly, 14 common concepts were extracted for the AI metamodel based on the existing literature. The metamodeling approach included as part of DSR was used to develop and validate the developed AI metamodel. In addition, the tracing technique was applied to validate the

effectiveness and capability of the developed AI metamodel. The AI metamodel developed for controlling and structuring the crisis management domain helps domain practitioners to develop their solution models easily based on their requirements. It can be used to identify potential risks and analyze the current state of the crisis. In addition, it is applicable to identifying the best strategies for crisis management and aids practitioners in the decision-making process. Furthermore, it can be used to identify the optimal solutions for a given problem; it helps to manage crises and improves the efficiency and accuracy of the crisis management domain.

Therefore, the AI metamodel developed in this study to control and structure the crisis management domain contributes to the body of relevant knowledge by:

- Assisting in making recommendations to optimize and enhance existing crisis management plans and procedures
- Identifying and assessing vulnerabilities in existing crisis management plans
- Automating the process of creating and maintaining detailed records of past crises and their resolutions
- Coordinating and managing cross-functional teams corresponding to crises

Compared to other current crisis management models, the established AI metamodel for controlling and structuring crisis management is relatively active. It helps to program diverse crisis management procedures so that the administration group could make more effective decisions. It also decreases the total time taken to classify the subjects to be addressed in a disaster. The metamodel also offers the management group understanding and leadership on how to efficiently achieve the state at hand. These additional resources enable the team to be more prepared and well-organized in their choices and activities. Finally, it offers a more organized approach to the crisis management process and has benefits in classifying the most effective results and plans in commerce with the disaster.

On the other hand, the developed AI metamodel for controlling and structuring crises is unique to other currently-used models in the sense that it can produce numerous description models from the abstract model. Dissimilar to outdated crisis management models that naturally follow predefined methods, the AI metamodel can analyze vast amounts of data. It can identify the underlying structures and develop tailored solution models based on the specific features and needs of each crisis. By instantiating several solution models from the abstract model, the AI metamodel offers a more flexible and complete crisis management method. It can consider different approaches, scenarios, and variables, allowing organizations to make more knowledgeable choices and respond efficiently to complex and growing crises.

Limitations of the Developed AI Metamodel

The established AI metamodel for controlling and structuring the crisis management field has some limitations, which include:

a) Incomplete data: The established AI metamodel relies on data for decision-making and problem-solving and the unavailability of complete data can limit its capability in making correct decisions
b) Incomplete customization: The established AI metamodels may not be able to acclimate to a diversity of disaster situations since their concepts may need to be regulated to cater to each new kind of state
c) The established AI metamodel may not be capable of explaining all the difficulties and gradations of the crisis management field. It may not be adequately nuanced to respond to nature types of disasters in an opportune and real method
d) The metamodel may not reflect social or party-political changes when annoying to reply to a disaster
e) The AI metamodel may fail to understand the import of confident statements or actions, which could constrain its capacity to respond quickly and precisely to a disaster
f) The AI metamodel may fail to explain the changeable nature of crises

Conclusion

Crisis management is the process of managing a situation or a business practice that has gone wrong and needs to be addressed quickly to prevent further damage. This involves assessing the situation, communicating with stakeholders, and implementing corrective and preventative measures to mitigate the risk of reoccurrences of similar incidents in the future. Crisis management plans are typically written in advance and include procedures for responding to and recovering from the crisis in an effective and timely manner. In this study, the AI metamodel was developed for controlling and structuring different kinds of crisis management based on the metamodeling approach. The developed AI metamodel consists of 14 common concepts which allow domain practitioners to establish several solution models based on their requirements. Furthermore, the effectiveness and completeness of the developed AI metamodel were validated using the tracing technique. In future work, the developed AI metamodel should be further tested and implemented in real scenarios to ensure its robustness. It also needs to be further evaluated to determine its accuracy and performance quality in crisis

management. In addition, the metamodel should be extended to include more concepts that are specific to different types of crises. Therefore, the metamodel should be integrated with other systems such as the Decision Support Systems (DSS) and Crisis Management Systems (CMS) to improvise the overall crisis management systems in organizations.

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Ethics

It is the first time that the article undersigned has appeared anywhere else in the world.

References

Abd Razak, S., Nazari, N. H. M., & Al-Dhaqm, A. (2020). Data anonymization using pseudonym system to preserve data privacy. *IEEE Access*, *8*, 43256-43264. https://doi.org/10.1109/ACCESS.2020.2977117

Abd Razak, S., Othman, S. H., Aldolah, A. A., & Ngadi, M. A. (2016). Conceptual investigation process model for managing database forensic investigation knowledge. *Research Journal of Applied Sciences, Engineering and Technology*, *12*(4), 386-394. https://doi.org/10.19026/rjaset.12.2377

AL-Dhaqm, A. M. R. (2019). *Simplified Database Forensic Invetigation Using Metamodeling Approach* (Doctoral dissertation, Universiti Teknologi Malaysia). http://eprints.utm.my/id/eprint/98147/1/ArafatMohammedRashadPSC2019.pdf

Al-Dhaqm, A. M. R., Othman, S. H., Abd Razak, S., & Ngadi, A. (2014, August). Towards adapting metamodelling technique for database forensics investigation domain. In *2014 International Symposium on Biometrics and Security Technologies (ISBAST)* (pp. 322-327). IEEE. https://doi.org/10.1109/ISBAST.2014.7013142

Al-Dhaqm, A., Abd Razak, S., & Othman, S. H. (2015). Common Investigation Process Model for Database Forensic Investiga-tion Discipline. In *the 1st ICRIL-International Conference on Innovation in Science and Technology, Kuala Lumpur, Malaysia* (pp. 297-300). https://core.ac.uk/reader/83531920

Al-Dhaqm, A., Razak, S., & Othman, S. H. (2018, November). Model derivation system to manage database forensic investigation domain knowledge. In *2018 IEEE Conference on Application, Information and Network Security (AINS)* (pp. 75-80). IEEE. https://doi.org/10.1109/AINS.2018.8631468

Al-Dhaqm, A., Razak, S., Ikuesan, R. A., R. Kebande, V., & Hajar Othman, S. (2021a). Face validation of database forensic investigation metamodel. *Infrastructures*, *6*(2), 13. https://doi.org/10.3390/infrastructures6020013

Al-Dhaqm, A., Ikuesan, R. A., Kebande, V. R., Abd Razak, S., Grispos, G., Choo, K. K. R., ... & Alsewari, A. A. (2021b). Digital forensics subdomains: The state of the art and future directions. *IEEE Access*, *9*, 152476-152502. https://doi.org/10.1109/ACCESS.2021.3124262

Al-Dhaqm, A., Othman, S. H., Yafooz, W. M., & Ali, A. (2023a). Review of Information Security Management Frameworks. In *Kids Cybersecurity Using Computational Intelligence Techniques* (pp. 69-80). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-21199-7_5

Al-Dhaqm, A., Yafooz, W. M., Othman, S. H., & Ali, A. (2023b). Database Forensics Field and Children Crimes. In *Kids Cybersecurity Using Computational Intelligence Techniques* (pp. 81-92). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-21199-7_6

Alfadli, I. M., Ghabban, F. M., Ameerbakhsh, O., AbuAli, A. N., Al-Dhaqm, A., & Al-Khasawneh, M. A. (2021, June). Cipm: Common identification process model for database forensics field. In *2021 2nd International Conference on Smart Computing and Electronic Enterprise (ICSCEE)* (pp. 72-77). IEEE. https://doi.org/10.1109/ICSCEE50312.2021.9498014

Alhussan, A. A., Al-Dhaqm, A., Yafooz, W. M., Emara, A. H. M., Bin Abd Razak, S., & Khafaga, D. S. (2022a). A unified forensic model applicable to the database forensics field. *Electronics*, *11*(9), 1347. https://doi.org/10.3390/electronics11091347

Alhussan, A. A., Al-Dhaqm, A., Yafooz, W. M., Razak, S. B. A., Emara, A. H. M., & Khafaga, D. S. (2022b). Towards Development of a High Abstract Model for Drone Forensic Domain. *Electronics*, *11*(8), 1168. https://doi.org/10.3390/electronics11081168

Ali, A., Razak, S. A., Othman, S. H., & Mohammed, A. (2015, April). Towards adapting metamodeling approach for the mobile forensics investigation domain. In *International Conference on Innovation in Science and Technology (lICIST)* (p. 5).

Ali, A., Razak, S. A., Othman, S. H., & Mohammed, A. (2018). Extraction of common concepts for the mobile forensics domain. In *Recent Trends in Information and Communication Technology: Proceedings of the 2nd International Conference of Reliable Information and Communication Technology (IRICT 2017)* (pp. 141-154). Springer International Publishing. https://doi.org/10.1007/978-3-319-59427-9_16

Ali, A., Razak, S. A., Othman, S. H., Marie, R. R., Al-Dhaqm, A., & Nasser, M. (2021, December). Validating Mobile Forensic Metamodel Using Tracing Method. In *International Conference of Reliable Information and Communication Technology* (pp. 473-482). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-98741-1_39

Ali, M. B., & Wood-Harper, T. (2022). Artificial Intelligence (AI) as a decision-making tool to control crisis situations. *Future Role of Sustainable Innovative Technologies in Crisis Management*, 71-83. https://doi.org/10.4018/978-1-7998-9815-3.ch006

Alotaibi, F. M., Al-Dhaqm, A., & Al-Otaibi, Y. D. (2022a). A Novel Forensic Readiness Framework Applicable to the Drone Forensics Field. *Computational Intelligence and Neuroscience*, *2022*. https://doi.org/10.1155/2022/8002963

Alotaibi, F. M., Al-Dhaqm, A., Al-Otaibi, Y. D., & Alsewari, A. A. (2022b). A comprehensive collection and analysis model for the drone forensics field. *Sensors*, *22*(17), 6486. https://doi.org/10.3390/s22176486

Ameerbakhsh, O., Ghabban, F. M., Alfadli, I. M., AbuAli, A. N., Al-Dhaqm, A., & Al-Khasawneh, M. A. (2021, June). Digital forensics domain and metamodeling development approaches. In *2021 2nd International Conference on Smart Computing and Electronic Enterprise (ICSCEE)* (pp. 67-71). IEEE. https://doi.org/10.1109/ICSCEE50312.2021.9497935

Antunes, G., Caetano, A., Bakhshandeh, M., Mayer, R., & Borbinha, J. (2013). Using ontologies to integrate multiple enterprise architecture domains. In *Business Information Systems Workshops: BIS 2013 International Workshops, Poznań, Poland, June 19-20, 2013, Revised Papers 16* (pp. 61-72). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-41687-3_8

Atkinson, C., & Kuhne, T. (2003). Model-driven development: A metamodeling foundation. *IEEE Software*, *20*(5), 36-41. https://doi.org/10.1109/MS.2003.1231149

Baras, D. S. A., Othman, S. H., Al-Dhaqm, A., & Radzi, R. Z. R. M. (2021, October). Information Security Management Metamodel (ISMM) Validation and Verification through Frequency-based Selection Technique. In *2021 International Conference on Data Science and Its Applications (ICoDSA)* (pp. 292-297). IEEE. https://doi.org/10.1109/ICoDSA53588.2021.9617527

Benaben, F., Lauras, M., Fertier, A., & Salatgé, N. (2019, December). Integrating model-driven engineering as the next challenge for artificial intelligence–Application to risk and crisis management. In *2019 Winter Simulation Conference (WSC)* (pp. 1549-1563). IEEE. https://doi.org/10.1109/WSC40007.2019.9004828

Benaben, F., Fertier, A., Montarnal, A., Mu, W., Jiang, Z., Truptil, S., ... & Lamothe, J. (2020). An AI framework and a metamodel for collaborative situations: Application to crisis management contexts. *Journal of Contingencies and Crisis Management*, *28*(3), 291-306. https://doi.org/10.1111/1468-5973.12310

Bénaben, F., Hanachi, C., Lauras, M., Couget, P., & Chapurlat, V. (2008, May). A metamodel and its ontology to guide crisis characterization and its collaborative management. In *Proceedings of the 5th International Conference on Information Systems for Crisis Response and Management (ISCRAM), Washington, DC, USA, May* (pp. 4-7).

Bennani, S., Maalel, A., Ghézala, H. B., & Abed, M. (2017, October). Towards a decision support model for the resolution of episodic problems based on ontology and case bases reasoning: Application to terrorism attacks. In *2017 IEEE/ACS 14th International Conference on Computer Systems and Applications (AICCSA)* (pp. 1502-1509). IEEE. https://doi.org/10.1109/AICCSA.2017.152

Casado, R., Rubiera, E., Sacristan, M., Schütte, F., & Peters, R. (2015). Data interoperability software solution for emergency reaction in the Europe Union. *Natural Hazards and Earth System Sciences*, *15*(7), 1563-1576. https://doi.org/10.5194/nhess-15-1563-2015

Cetinkaya, D., & Verbraeck, A. (2011, December). Metamodeling and model transformations in modeling and simulation. In *Proceedings of the 2011 Winter Simulation Conference (WSC)* (pp. 3043-3053). IEEE. https://doi.org/10.1109/WSC.2011.6148005

Elmhadhbi, L., Karray, M. H., & Archimède, B. (2019, May). A modular ontology for semantically enhanced interoperability in operational disaster response. In *16th International Conference on Information Systems for Crisis Response and Management-ISCRAM 2019* (pp. 1021-1029). https://hal.science/hal-02487086/

Essien, A. E., & Petrounias, I. (2022). An Artificial Intelligence (AI)-Based Decision-Making Framework for Crisis Management. In *Future Role of Sustainable Innovative Technologies in Crisis Management* (pp. 84-98). IGI Global. https://doi.org/ 10.4018/978-1-7998-9815-3.ch007

Fan, Z., & Zlatanova, S. (2011). Exploring ontologies for semantic interoperability of data in emergency response. *Applied Geomatics*, *3*, 109-122. https://doi.org/10.1007/s12518-011-0048-y

Farrokhi, A., Shirazi, F., Hajli, N., & Tajvidi, M. (2020). Using artificial intelligence to detect crisis related to events: Decision making in B2B by artificial intelligence. *Industrial Marketing Management*, *91*, 257-273. https://doi.org/10.1016/j.indmarman.2020.09.015

Ghabban, F. M., Alfadli, I. M., Ameerbakhsh, O., AbuAli, A. N., Al-Dhaqm, A., & Al-Khasawneh, M. A. (2021, June). Comparative analysis of network forensic tools and network forensics processes. In *2021 2nd International Conference on Smart Computing and Electronic Enterprise (ICSCEE)* (pp. 78-83). IEEE. https://doi.org/10.1109/ICSCEE50312.2021.9498226

Gichuhi, J. M., Oginde, D., & Wambua, P. (2023). The relevance of crisis planning and organizing in realisation of organizational resilience: lessons from telecommunication companies in Kenya. *International Academic Journal of Human Resource and Business Administration*, *4*(2), 145-167. http://www.iajournals.org/articles/iajhrba_v4_i2_145_167.pdf

Han, Y., & Xu, W. (2015, November). An ontology-oriented decision support system for emergency management based on information fusion. In *Proceedings of the 1st ACM SIGSPATIAL International Workshop on the Use of GIS in Emergency Management* (pp. 1-8). https://doi.org/10.1145/2835596.2835602

Khalifa, M., Al Baz, M., & Muttar, A. K. (2022). The Impact of Applying Artificial Intelligence on Human Resources Crisis Management: An Analytical Study on COVID19. *Information Sciences Letters*, *11*(1), 269-276. https://digitalcommons.aaru.edu.jo/cgi/viewcontent.cgi?article=1248&context=isl

Kruchten, P., Woo, C., Monu, K., & Sotoodeh, M. (2008). A conceptual model of disasters encompassing multiple stakeholder domains. *International Journal of Emergency Management*, *5*(1-2), 25-56. https://doi.org/10.1504/IJEM.2008.019906

Lauras, M., & Comes, T. (2015). Special issue on innovative artificial intelligence solutions for crisis management. *Engineering Applications of Artificial Intelligence*, *46*(Part B, SI), p-287. https://hal.science/hal-01609212

Leachu, S., Berninger, S., & Janßen, J. (2022). AI-Based Crisis Management Utilizing Scenarios. https://epub.fir.de/frontdoor/index/index/docId/1784

Mughal, M. H., Shaikh, Z. A., Khand, Z. H., Rajput, A., & Akhtar, F. (2021). A Systematic Review of Ontology-Based River Streamflow and Flood Data Management Challenges. *Quaid-E-Awam University Research Journal of Engineering, Science & Technology, Nawabshah.*, *19*(1), 40-50. https://doi.org/10.52584/QRJ.1901.06

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of management information systems*, *24*(3), 45-77. https://doi.org/10.2753/MIS0742-1222240302

Saleh, M. A., Othman, S. H., Al-Dhaqm, A., & Al-Khasawneh, M. A. (2021, June). Common investigation process model for Internet of Things forensics. In *2021 2nd International Conference on Smart Computing and Electronic Enterprise (ICSCEE)* (pp. 84-89). IEEE. https://doi.org/10.1109/ICSCEE50312.2021.9498045

Saleh, M., Othman, S. H., Driss, M., Al-Dhaqm, A., Ali, A., Yafooz, W. M., & Emara, A. H. M. (2023). A Metamodeling Approach for IoT Forensic Investigation. *Electronics*, *12*(3), 524. https://doi.org/10.3390/electronics12030524

Salem, M., Othman, S. H., Al-Dhaqm, A., & Ali, A. (2023). Development of Metamodel for Information Security Risk Management. In *Kids Cybersecurity Using Computational Intelligence Techniques* (pp. 243-253). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-21199-7_17

Wrzalik, A., & Jereb, B. (2019). Use of expert systems in crisis management. *System Safety: Human-Technical Facility-Environment*, *1*(1), 406-411. https://doi.org/10.2478/czoto-2019-0052

Yafooz, W. M., Al-Dhaqm, A., & Alsaeedi, A. (2023). Detecting Kids Cyberbullying Using Transfer Learning Approach: Transformer Fine-Tuning Models. In *Kids Cybersecurity Using Computational Intelligence Techniques* (pp. 255-267). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-21199-7_18

Zawali, B., Ikuesan, R. A., Kebande, V. R., Furnell, S., & A-Dhaqm, A. (2021). Realising a push button modality for video-based forensics. *Infrastructures*, *6*(4), 54. https://doi.org/10.3390/infrastructures6040054