From Data to Action: A Graph-Based Approach for Decision Support in Civil Protection Operations Planning

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ABSTRACT

In the face of increasing frequency and severity of crises such as natural disasters, pandemics, and geopolitical conflicts, civil protection organizations are crucial for recovery and support for affected populations. However, the efficiency and effectiveness of these organizations in crisis response are often hindered by the manual generation of operation plans, characterized by cognitive overload and limited analytic overview. Existing systems focus on detecting crises or post-crisis analysis, overlooking proactive planning. We present GRETA, a graph-based operational planning approach utilizing semantic historical data for better decision support. GRETA uses Operational Scenario Patterns to model operations, mapping them onto a knowledge graph in JSON-LD format, thus creating a structured representation of past data to improve future crisis response planning. We tested GRETA with Germany's Federal Agency for Technical Relief, analyzing over 157,450 historic operations from 2012-2022. Results show GRETA enhances plan efficiency, accuracy, and comprehensiveness, aiding especially inexperienced planners.

Keywords

Operations Planning, Civil Protection, Decision Support Systems, Knowledge Graph, Operational Scenario Patterns

INTRODUCTION

In recent years crises like natural disasters, pandemics or political conflicts are becoming more frequent with critical impacts on people's private and public lives, finances, economy and politics, for instance the COVID-19 pandemic, the Turkey–Syria earthquakes in 2023 or the Russian Ukrainian war. In such crisis situations, civil protection organizations like the German Federal Agency for Technical Relief (THW), French Civil Protection, Corps of the Italian Civil Protection or the Austrian Red Cross restore order, rebuild affected areas and provide support for civilians and crisis victims (Chehade et al., 2018; Habib et al., 2018; Idris and Soh, 2014; Wrona et al., 2019). To ensure efficient and effective operations on-site, accurate and complete operation plans for task-driven allocation of

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resources and qualified personnel are needed as fast as possible (Idris and Soh, 2014). Currently, those operation plans are generated manually by experts including all related disadvantages of human cognitive overload under time pressure as well as limited analytic overview due to heterogeneous large-scale data (Correia et al., 2018). Up til now, data-driven decision support systems are not applied within operations planning of civil protection organizations in Germany.

This leads to an inefficient use of resources, delayed responses by civil protection organizations and, in the worst case, less saved lives (Ali, 2015; Idris and Soh, 2014).

Existing approaches on decision support systems for operations planning focus on early detection of crisis signals (e.g, Bompotas et al., 2022), post-crisis planning recommendations (e.g., Krstikj et al., 2021; Lindner et al., 2018; Rauchecker and Schryen, 2018), logistical topics such as optimized route planning for resource deployment (Lim et al., 2017), evacuation plans (Lee et al., 2017), or usage of robots and drones (Habib et al., 2018). Supporting the upfront planning process of operations is beyond the scope of these approaches. In our research, we investigate decision support systems for operations planning for upcoming crisis events.

In this work-in-progress paper, we present GRETA - a graph-based approach for operations planning based on semantically enhanced historical data. GRETA introduces Operational Scenario Patterns that extend existing approaches on representing crisis events (e.g., Janzen et al., 2023) with respect to domain knowledge about operations in civil protection. Those patterns are used for mapping and aggregating large-scale data on historical crisis operations onto a knowledge graph operationalized on JSON-LD. Framed as a kind of episodic knowledge representation of past operations, the resulting knowledge graph can be used in a decision support system to generate recommendations for operation plans for upcoming crisis events.

GRETA was instantiated and evaluated in a concrete use case with the civil protection organization THW addressing planning officers on regional and supraregional levels. The applied data set covered #157,450 historic THW operations within Germany (2012-2022), including details on crisis events with respect to location and type, requester and planner of operation, date, planned duration, report on tasks, number of helpers etc. Within the case study, we showed the potential of GRETA for supporting operations planning in civil protection in terms of required time (efficiency), accuracy and completeness of resulting plans (effectiveness) as well as the empowerment of less-experienced planning officers.

RELATED WORK

Related work on graph-based decision support in crisis management (Kontopoulos et al., 2018) focus on semantic representations of specific crisis domains, e.g., fire, hazard crises or earthquakes, but not on operations (Chehade et al., 2018; Gaur et al., 2019; Hassan and Chen-Burger, 2016). Existing ontologies in the crises domain like EMERGEL[1] and MOAC[2] are not available online. Other graph-based approaches focus on natural language processing for knowledge extraction from unstructured operation descriptions in the context of military operations Zhao et al., 2022. The generation of recommendations for upcoming operations with respect to required personnel, equipment, tasks, duration etc. is beyond the scope of those approaches; as well as the usage of structured and unstructured data in decision-making for improving operations planning and thereby resilience of civil protection organizations (Shittu et al., 2018).

GRAPH-BASED APPROACH FOR OPERATIONS PLANNING IN CIVIL PROTECTION

We present GRETA, a graph-based approach for operations planning in civil protection consisting of four main modules (cf. Fig. 1): **Mapper, Neo4j Inserter, Query Builder,** and **Recommender**. Core concept of GRETA are graph-based operational scenario patterns following Chehade et al., 2018; Gaur et al., 2019; Hassan and Chen-Burger, 2016; Janzen et al., 2023; Kontopoulos et al., 2018; Mescherin et al., 2013 (cf. Fig. 2). Fig. 3 shows all entities and attributes of the operational scenario pattern as well as applied concepts of foundational ontologies and the transfer to domain-specific items in the use case (THW data). As an **identifier** of an operation, an ID or the date of the operation is used. In addition to a description of the crisis event, the pattern covers a **context** entity for specifying the event type of the crisis (e.g., natural distasters) and the concrete event (e.g., flood) (cf. Fig. 2). As defined in Janzen et al., 2023, the operational scenario pattern includes a **provenance** entity for capturing the source of crisis information and operation request as well as an entity for the **location** of the operation. If an operation was part of a greater project, this information is represented within the precondition attribute in the **reason** entity (cf. Fig. 3). **Impact** of an operation is described by the attributes duration of the operation, post-conditions (e.g., final report of operation) and the severity of the operation. The **actors** entity covers information on the total amount of actors (helpers) of the operation, their conducted working hours as well as deployed units with their strengths, roles

[1] http://disaster-fp7.eu/sites/default/files/D3.22.pdf
[2] http://observedchange.com/moac/ns

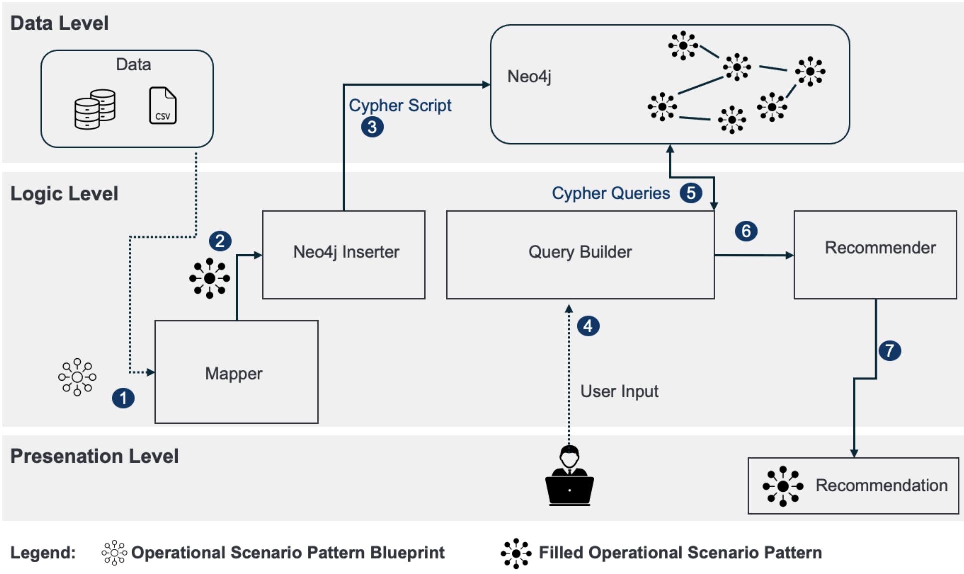

Figure 1. Graph-based Approach for Operations Planning in Civil Protection (GRETA)

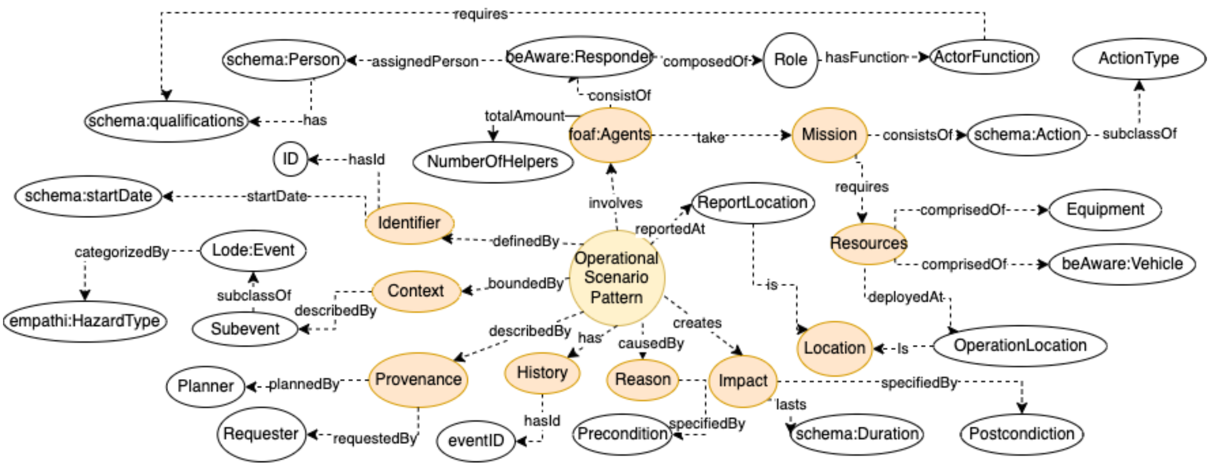

Figure 2. Graph-based view of Operational Scenario Pattern (Extract)

and assigned helpers per role (cf. Fig. 2). Furthermore, actions to be fulfilled in the operation are captured by the **missions** entity in form of action types as well as action sets per type. Vehicles required in operations are covered by the entity **resources**. Last, based on event type and location of the crisis (context), operational scenario patterns are interlinked by their identifiers within the **history** entity. All entities are anchored in and mapped onto existing vocabularies and ontologies (e.g. foaf[3], beAware[4], LODE[5], Empathi[6], DCAT[7], schema.org[8]) (cf. Fig. 3). GRETA applies the operational scenario pattern blueprint for mapping historic data on past operations on a knowledge graph with episodic operational knowledge (cf. Fig. 1). First, pre-processed data of historic operations in csv-format are mapped onto an operational scenario pattern blueprint in JSON-LD format by the Mapper component (cf. Fig. 1, step 1). Thereby, filled operational scenario pattern, means interlinked historic data are generated that are pushed to the Neo4j Inserter (cf. Fig. 1, step 2). By means of a cypher script the filled operational scenario patterns are inserted into Neo4j as knowledge base repository (cf. Fig. 1, step 3). Using JSON-LD as format has several advantages. First, the data entered into the knowledge graph can be easily expanded using other available data sets described by existing ontological standards. In addition, data of civil protection organizations such as the German Federal Agency for Technical Relief (THW) is currently only available in CSV format. However, CSV is not suitable

[3]http://xmlns.com/foaf/0.1/
[4]https://github.com/beAWARE-project/ontology
[5]https://linkedevents.org/ontology
[6]https://w3id.org/empathi/1.0
[7]http://www.w3.org/ns/dcat
[8]http://schema.org

Entities	Attributes	THW Data	Ontology Mapping
Identifier	ID, start date, end date	ID, start, end	-, schema:startDate, schema:endDate
Context	Event type, event, description	Event type, event, description of event	empathi:HazardType, Lode:Event, schema:description
Provenance	Planning Organization, Requesting Organization	Planner & requester	schema:Organization
Location	Regional area, federal state, city, country	Regional area, federal state, city, country	schema:addressRegion, schema:State, schema:addressLocality, schema:addressCountry
Reason	Preconditions	Service project	-
Impact	Duration, Postconditions, severity	Planned duration, report of operation	schema:duration, empathi:Severity
Actors	Total number of actors, workhours, unit, strength, role, helpers per role	Number of helpers, workhours, units, strength, function, Number of helpers needed per function	foaf:Agent,-, -,beAWARE:Responder, -, -
Mission	Action type, action set	Task, task description	beAWARE: Mission,-, schema:action
Resources	Vehicles	Vehicles	beAWARE: Vehicle
History	Scenario ID	Historical IDs	-

Figure 3. Operational Scenario Pattern

for mapping nested tree-like structures as presented by civil protection units. JSON-LD enables to keep important structural and semantic information between units, functions, their tasks to be performed and required qualifications that are transferred to the knowledge graph. This in turn enables further completion of meanwhile unconnected individual datasets through inferencing and a deeper analysis of the data records with regard to graph metrics, e.g. to recognize key personnel via the number of connected nodes and edges for certain events. The episodic representation of operational knowledge can then be requested using cypher queries by means of the Query Builder (cf. Fig. 1, step 4 and 5). To give an example, the following query extracts information on actors connected to a specified event: `MATCH (osp:OperationalScenarioPattern)-[:t_bounded_by]-(c:Context)-[:t_described_by]-(s:Subevent) WHERE s.name =~ "(?i).*$SUBEVENT_NAME.*") WITH sp MATCH (sp)-[:t_involves]-(i:Actors) RETURN distinct(i)`.The resulting output is processed by the Query Builder and aggregated to planning recommendations by the Recommender (cf. Fig. 1, step 6 and 7). Recommendations are structured according to a subset of operational scenario patterns; here the entities Actors and Impact are used to present results (cf. Fig. 4). GRETA was implemented as a web-based service using HTML, JavaScript, JSON-LD, Neo4j[9] [10].

USE CASE

We instantiated and evaluated GRETA in a concrete use case with the German Federal Agency for Technical Relief (THW) - an agency of the German Federal Ministry of Interior and Community. THW operations include for instance debris clearance, electricity supply, bridge building or logistics, serving the purpose of maintaining public structures and critical infrastructure. Currently, the operations planning process at THW is deployed manually by experts. Although, THW collects data on larger missions, data about included operations differ with respect to formats and details of fulfilled operation tasks etc. Up til now, available data are therefore of limited usefulness for planning experts when allocating tasks and personnel to upcoming operations. Furthermore, structured data on historic operations including allocated units and tasks are not accessible at all via the internal IT infrastructure. This information is embedded in heterogeneous, unstructured textual documentations that do not offer direct added value in the effective and efficient planning of operations under time pressure of an expected crisis event. Within the use case, a data set covering #157,450 historic THW operations within Germany (2012-2022) was used as input for GRETA, including details on crisis events with respect to location and type, requester and planner of operation, date, planned duration, report on tasks, number of helpers etc.

[9] https://github.com/InformationServiceSystems/pairs-project/blob/main/Modules/THW
[10] https://www.youtube.com/watch?v=ohWVGATnjZM&t=1s

Entities	Attributes	Recommendation
Actor	TotalNumberOfHelpers	12
		135
	Responders	'Debris Clearance', 'Technical Unit Waterdamage/Pumping', 'Diving Group', 'Bridge Construction Group', 'Emergency supply and repair', 'Locating group', 'Technical Platoon'
Impact	Duration	0:10:32:08

Figure 4. Recommendation for operation plan for upcoming crisis event based on user input "flood" as *event type* and "secure operation site" as *action type*

Data Preparation

In order to enable the mapping of the historic operations data to operational scenarios patterns (cf. Fig. 2), the data set was prepared, i.e., we (1) collected, (2) cleaned, and (3) merged the data entries to generate a comprised data set.

(1) Collecting data: Initially, the data set included details on the crisis event such as location and type, the fulfilled operation, requester and planner, date, planned duration, a short report (description), number of deployed helpers, internal operation ID, provided service and assigned service project. For adding missing information on involved units and vehicles of the historic operations, an available tool developed by THW was used for extraction[11]. The extracted data covered details about tasks associated with over 40 units and details on 57 vehicle types. Additionally, 47 strength and equipment certification documents (StAN) were transformed into a structured data set for extending the data set with information on assigned roles and vehicles per unit.
(2) Cleaning data: The resulting data set was cleaned by deleting rows with missing features, merging operations with the same internal ID and correcting features with deviant formats and broken entries (e.g., dates, planned duration). As a result, the cleaned data set covered #31,118 operations.
(3) Merging data: In order to be able to inference on deployed units, tasks and vehicles per historic operation, collected data sets were merged using the BERT model (Reimers and Gurevych, 2019). Embeddings of operation descriptions and tasks associated with units as well as vehicles were generated. Furthermore, cosine similarity was used to establish a relationship between operations units based on unit's potential tasks and the tasks conducted within the operations. By testing diverse thresholds, we found an acceptable trade-off between the number of data entries and an accurate allocation of units per operation (confidence score: 60%). As a result, the integrated data set consisted of #15,274 historic operations.

THW Operations Planning Supported by GRETA

The pre-processed data set of #15,274 THW operations was mapped onto the operational scenario pattern blueprint in JSON-LD by the Mapper component of GRETA. Fig. 3 shows the mapping relations between entities of the pattern to THW data features. Resulting filled operational scenario patterns, i.e., historic THW operations are generated, pushed to the Neo4j Inserter and inserted into a knowledge graph (cf. Fig. 1). Giving an exemplary user request for planning an operation of the *event type:"flood"* and the *action type:"secure operation site"*, this input is translated into a cypher query by means of the Query Builder. The resulting output covers #306 relevant historic operations that are processed by the Query Builder, e.g., for inferencing the appropriate number of helpers, planned duration for the operation to be planned based on the historic data. The extracted data are aggregated to an operations plan recommendation based on the structure of the operations scenario pattern by the Recommender component, i.e., the entities actors and impact are used to present recommendation results (cf. Fig. 4). Given the exemplary user input, GRETA recommended to staff the planned operation with 12 helpers with 135 hours potential working time based on an expected operation duration of 10 hours and 32 minutes. Furthermore, units are listed that are required for conducting the operation, e.g., debris clearance, and bridge construction group (cf. Fig. 4).
Generated results are represented within a first prototypical service, that is available as open source code on Github[12]. The user interface comprises four tabs (cf. Fig. 5). Two tabs are used to describe the service and applied Operational Scenario Patterns (1) Introduction & Data, (2) Background Information, while the remaining two tabs serve as the main functionalities of the service (3) Event Prediction, (4) Recommendations. Based on the amount of data per individual crisis event, that was available to train our predictive machine learning forecasting model, the event prediction focuses on weather-based events, in particular floods, heavy rainfall and snowfall within Germany.

[11] https://gitlab.com/Manuel_Raven/dienststellen-scraper-extended
[12] https://github.com/InformationServiceSystems/pairs-project/blob/main/Modules/THW

Figure 5. Overview of the user interface for the implemented web service of GRETA

After selecting the desired location, the user receives information on the occurrence (red dots) of predicted events for the next 7 days, as well as a risk assessment for the forecast via the confidence of the forecasting model and a threshold value (orange line). In addition, a map-based area overview provides topographical information and current weather information on selected locations. Planning recommendations are generated for the selected location and predicted crisis events and an additionally selected task category. The recommendations include a classification of the event, contextual information on similar past incidents, recommendations for action, personnel recommendations and resource recommendations per unit. A demo of the service is also available on Youtube [13].
Within the case study, we showed the potential of GRETA for supporting operations planning in civil protection in terms of required time (efficiency), accuracy and completeness of resulting plans (effectiveness) as well as the empowerment of less-experienced planning officers. In contrast to actual dispersed data and isolated documents at THW, operational scenario patterns supports structuring available data of past operations by means of a linked data approach (JSON-LD) and improves the accessibility of existing operational knowledge. Furthermore, GRETA offers the opportunity to interlink operational knowledge by diverse civil protection organization by applying operational scenario patterns on their data enabling a cross-organizational operational knowledge space for more efficient collaboration in operations planning and conduction.

LIMITATIONS AND FUTURE WORK

While GRETA demonstrates promising results in enhancing operations planning for civil protection organizations, there are also several limitations. The effectiveness of GRETA heavily relies on the quality and completeness of historical data. Incomplete or inaccurate data may lead to suboptimal recommendations. Future work should focus on improving the data collection methods and ensuring data accuracy to enhance the reliability of GRETA (cf. section on data preparation for the use case). The scalability of GRETA in handling larger datasets and diverse crisis scenarios needs further investigation. As the volume and complexity of crisis events increase, the scalability of GRETA's knowledge graph construction and recommendation generation processes may become a bottleneck. Future research should explore strategies for optimizing GRETA's performance on larger datasets also with respect to cross-organizational operation planning based on shared data on historic operations.
While GRETA utilizes operational scenario patterns to represent domain knowledge, there may still be nuances specific to civil protection operations that are currently not adequately captured. Enhancing the domain-specific knowledge representation within GRETA could lead to more accurate and tailored recommendations for operations planning. Those aspects will be investigated in an empirical user study with the resulting prototype with experienced planning officers by THW. In this study also the usability and adoption of GRETA by planning officers will be evaluated in real-world settings as those are crucial factors for its practical utility.
Furthermore, GRETA primarily relies on historic data for generating operation plans. Integrating real-time data streams, such as weather data, social media feeds or sensor data (e.g., water level of rivers), could further enhance GRETA's capabilities by providing up-to-date information on unfolding crisis events and potentially required operations. Future research will explore methods for integrating real-time data and generate predictions for potential crisis events by applying machine learning methods (e.g., XGBoost) into the decision support system based on GRETA.

[13] https://www.youtube.com/watch?v=ohWVGATnjZM&t=1s

CONCLUSION

In this paper, we introduced GRETA, a graph-based approach for enhancing operations planning in civil protection organizations. By leveraging semantically enhanced historic data and operational scenario patterns with linked data, GRETA provides decision support for generating operation plans for upcoming crisis events. Through a case study with the German Federal Agency for Technical Relief (THW), we demonstrated the potential of GRETA in improving the efficiency, accuracy, and completeness of operation plans, while empowering especially less-experienced planning officers.

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